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Corresponding Editor	Family Name	**Nadykto**
	Particle	
	Given Name	**Volodymyr**
	Suffix	
	Division	
	Organization	Tavria State Agrotechnological University
	Address	Melitopol, Ukraine
	Email	vmz@tsatu.edu.ua

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Volodymyr Nadykto
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Trends and Innovations

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Editor
Volodymyr Nadykto
Tavria State Agrotechnological University
Melitopol, Ukraine

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Contents

Part I

Improving the Efficiency of Fruit Tree Sprayers 3
Nikolai Struchaiev, Larysa Bondarenko, Olexandr Vershkov and Andrei Chaplinskiy

Refractory Materials Manufacturing Based on Sewage Sludge 11
Ludmyla Chernyshova, Sergei Kurchev, Oleg Peniov and Vitaliy Cherkun

Increasing the Efficiency of the Technological Process of Processing Castor-Oil Seeds into Castor Oil 17
Volodymyr Didur, Volodymyr Kyurchev, Andriy Chebanov and Anatoliy Aseev

Mechanism for the Maintenance of Investment in Agriculture 29
Halyna Hrytsaienko, Igor Hrytsaienko, Andrey Bondar and Dmitry Zhuravel

Location of Social Capital in the Labor Protection of the Enterprise 41
Mykola Hrytsaienko, Yuri Rogach and Mykhailo Zorya

Defining Stability of Technological Process of Growing Fruit Crop Seedlings 53
Aleksander Karaiev, Ludmila Tolstolik, Ivan Chyzhykov and Tatiana Karaieva

Design of Functional Surfaces in CAD System of SolidWorks via Specialized Software 63
Yuliia Kholodniak, Yevhen Havrylenko, Iryna Pykhtieieva and Viktor Shcherbyna

Seed Material Size Influence on Its Uniform Sowing Unit Delivery 75
Volodymyr Kiurchev, Yevhenii Serbii and Svitlana Shevchenko

AQ1

Agrobiological as Well as Mechanical and Technological Framework of Development of the Harvesting Technology with the Method of Grain Crops Combing in Standing Position 85
Aleksandr Lezhenkin, Ivan Lezhenkin, Aleksandr Vershkov and Sergey Kolomiyets

Simulation of Cereal Crops Harvesting Using the Method of Grain Crops Combing in Standing Position in Conditions of Farming Enterprises 91
Aleksandr Lezhenkin, Ivan Lezhenkin, Aleksandr Vershkov and Sergey Kolomiyets

Software Development for the Security of TCP-Connections 99
Dmytro Lubko, Sergii Sharov and Oksana Strokan

The Formation of Orthogonal Balanced Experiment Designs Based on Special Block Matrix Operations on the Example of the Mathematical Modeling of the Pneumatic Gravity Seed Separator 111
Vira Malkina, Sergey Kiurchev, Viacheslav Osadchyi and Oksana Strokan

The Parameters Substantiation of Seed Drill Capacity for Stone Crop Seeds 121
Oleksandr Matkovskyi, Aleksander Karaiev, Sergii Sankov and Tatiana Karaieva

Methodological Aspects of Determining Parameters of a Scalper-Type Air-Sieved Separator Airflow 133
Evgeniy Mikhailov, Marina Postnikova, Natalia Zadosnaia and Oleg Afanasyev

Theoretical Aspects of Plant Material Sealing in a Wedge-Shaped Canal 139
Dmytro Milko, Viacheslav Bratishko, Volodymyr Kuzmenko and Oleksandr Kholodiuk

Study of Hydromechanical Parameters Part of the Water Solutions Household in Running Flows 145
Serhii Movchan, Olena Dereza, Serhii Mazilin and Serhii Dereza

The Efficiency of Tractor Application with Articulated Frame for Cultivating Arable Crops 161
Vodymyr Nadykto, Olexandr Karaiev, Volodymyr Kyurchev and Hristo Beloev

Operating Conditions' Influence on the Change of Functional Characteristics for Mechatronic Systems with Orbital Hydraulic Motors 169
Anatolii Panchenko, Angela Voloshina, Irina Milaeva and Petro Luzan

Increase in Durability of Motor Crankshaft Pin Surface by Vibrorolling 177
Oleksii Novyk, Valeriia Panina, Halyna Dashyvets and Andriy Bondar

The Coefficient Determination of a Damper Washer Hydraulic Resistance for Reducing a Technical Module Oscillation Amplitude 183
Volodymyr Bulgakov, Oleksandr Parakhin, Vasil Mitkov and Tetiana Chorna

Generalization of Factors of Milk Homogenization 191
Kyrylo Samoichuk, Nadiia Zahorko, Vadym Oleksiienko and Serhii Petrychenko

Setting Ground Dimension-Type Series-Tillage Fertilizing, Sowing Complexes for Growing Grain Crops 199
Vitaliy Serbiy, Volodymyr Diuzhaiev, Galina Antonova and Olena Mykhailenko

Consulting Services in Agriculture 217
Nadiia Serskykh and Igor Britchenko

Development of Technology for the Hemp Stalks Preparation 223
Viktor Sheichenko, Igor Marynchenko, Vitaliy Shevchuk and Natalia Zadosnaia

Theoretical Studies of Stable Exploitation Conditions of a Three-Wheeled Tractor on the Field Slopes 233
Viktor Sheichenko, Gedal Hailis, Igor Dudnikov and Tetiana Chorna

Research of the Cereal Materials Micronizer for Fodder Components Preparation in Animal Husbandry 249
Alexander Skliar, Boris Boltyanskyi, Natalia Boltyanska and Denis Demyanenko

Grains Dynamic Strength Determination and the Optimal Combination of Components of a Diamondiferous Layer of Grinding Wheels 259
Olga Sushko, Serhii Kiurchev, Oleksandr Kolodii and Roman Bakardzhyiev

Application of Phenoclimatographic Models in Stone Fruits Protecting from Spring Frosts 267
Valentyna Odyntsova, Serhii Sushko, Larysa Bondarenko and Nina Scherbakova

Vacuum Cooling Technology for Pre-cooling of Cherry Fruits 281
Oleksandr Lomeiko, Lilia Yefimenko and Vira Tarasenko

Sowing Units for Drilling Vegetable Crops 289
Volodymyr Tarasenko, Larysa Bondarenko, Nina Scherbakova and Natalia Horbova

Examining the Creative Potential of Engineering Students 299
Natalia Sosnytska, Olena Titova, Svitlana Symonenko and Olena Kravets

Development of Communicative Competence as a Precondition of Competitive Software Engineer Formation 307
Svitlana Symonenko, Nataliia Zaitseva, Olena Titova and Margaryta Vynogradova

Analysis of Main Process Characteristics of Infrared Drying in the Moving Layer of Grain Produce 317
Igor Palamarchuk, Sergey Kiurchev, Lyidmila Kiurcheva and Valentyna Verkholantseva

Geometrical Parameters for Distribution Systems of Hydraulic Machines 323
Angela Voloshina, Anatolii Panchenko, Igor Panchenko and Andrii Zasiadko

Part II

Mathematical Model Changing the Value of the Process of Leakage Current in 0.38 kV Networks 339
Viacheslav Gerasymenko, Volodymyr Kozyrskyi, Natalia Maiborodina and Oleksandr Kovalov

Experimental Study of Positive Influence on Growth of Seeds of Electric Field a High Voltage 349
Vadim Hulevskyi, Yurii Stopin, Yulia Postol and Mariia Dudina

The Usage of Electricity Charged Aerosol for Greenhouse Cooling: Problems and Prospects 355
Anton Kashkarov, Volodymyr Diordiiev, Andrii Sabo, Gennadii Novikov and Olexandr Diordiiev

Development of a Motor Speed Observer for a Electrified Soil-Cultivating Motoblock 365
Oleksandr Kovalov, Sergy Kvitka, Oleksandr Solomakha and Vyacheslav Gerasymenko

Experimental Investigations of Functional Properties of Biofuel Processed in the Electrotechnological Complex 375
Kushlyk Ruslan, Nazarenko Igor and Kushlyk Roman

Hybrid Power System Stochastic Optimization 385
Olga Lysenko, Mykola Kuznetsov, Andriy Chebanov and Svitlana Adamova

Energy Saving in the Technological Process of the Grain Grinding 395
Marina Postnikova, Evgeniy Mikhailov, Dina Nesterchuk and Olga Rechina

Determination of the Duration of Spherical-Shaped Berries Freezing Under the Conditions Stationary Heat Flow 405
Nikolai Struchaiev, Yulia Postol, Yria Stepin and Ivan Borokhov

Energy-Saving Control of Asynchronous Electric Motors for Driving Working Machines 415
Oleksandr Vovk, Sergey Kvitka, Sergey Galko and Oleksandr Strebkov

Part III

The Role of Social Capital in Development of Agricultural Entrepreneurship 427
Mykola Hrytsaienko, Halyna Hrytsaienko, Larisa Andreeva and Larisa Boltyanska

Methodological Aspects of Forming Mathematic Models of Management of Socio-economic Systems Development 441
Oleksii Hudzynskyi, Yulia Hudzynska, Svitlana Sudomyr and Maria Sudomyr

Modeling Innovative Economic Activity of Peasant Farm 451
Sergey Kalchenko, Tetiana Popova, Denis Eremenko and Larisa Eremenko

Prospects of Ukraine on the World Market of Dairy Desserts 463
Tatiana Krasnoded, Tetiana Popova, Tetiana Bakina and Olena Vasylchenko

Cognitive Modeling in the Regional Strategic Management 473
Olha Nazarova, Elena Shevchuk, Svitlana Plotnichenko and Nonna Surzhenko

Managing Competitiveness of the Enterprise: Theoretical-Methodological Aspect 483
Svitlana Nesterenko, Svitlana Rozumenko, Oleg Kravets and Lyudmila Redko

International Ranking and Clustering Systems in Complex Evaluation of Demographic and Migration Processes 493
Svitlana Nesterenko, Dmytro Vasylkivskyi, Raisa Kvasnytska and Ihor Lapshyn

Ukraine in the Context of the World Organic Production of Agricultural Products 507
Roman Oleksenko, Iryna Kolokolchykova and Olena Syzonenko

Development and Incipience Decentralization of Authority in Ukraine and Formation of Its Impact on Local Budgets' Financial Capacity 515
Svitlana Osypenko, Inna Kohut, Olena Iatsukh and Elvina Abliazova

Analyses of Personnel Usage at Agricultural Enterprises 527
Yurii Prus, Tetiana Yavorska, Olena Voronianska and Olexiy Petryha

Methodical Approaches to Implementation of Financial Bank Stability 547
Nataliia Radchenko, Natalia Rubtsova, Iryna Chkan and Inna Yakysheva

Accounting and Analytical Methods for Identifying Risks of Agricultural Enterprises' Sustainable Development 561
Oleh Sokil, Zhuk Valeriy, Nataliia Holub and Olha Levchenko

Managing of the Living Quality of Population in the Social Sphere 571
Lyudmyla Synyayeva, Nataliya Bocharova, Iryna Ahieieva and Anhelina Yarchuk

Accounting Essence of Amortization Policy 583
Zhuk Valeriy, Trachova Dar'ya, Sakhno Ludmyla and Demchuk Olena

Problems and Prospects for Development of Family Households in Ukraine 593
Tetiana Yavorska, Yurii Prus, Oksana Lysak and Hanna Zavadskykh

Part IV

Comprehensive Assessment of the White Roots Aroma 605
Iryna Bilenka, Yana Golinskaya, Iryna Kalugina and Lyudmila Kiurcheva

Influence of the Growth Regulator Application Method on Antioxidant Plant System Activity of Winter Wheat (*Triticum Aestivum* L.) 615
Zoia Bilousova, Yuliia Klipakova, Victoria Keneva and Sergei Kuleshov

Effects of Different Dietary Selenium Sources Including Probiotics Mixture on Growth Performance, Feed Utilization and Serum Biochemical Profile of Quails 623
Volodimir Bityutskyy, Svitlana Tsekhmistrenko, Oksana Tsekhmistrenko, Olexander Melnychenko and Viktor Kharchyshyn

Influence of Oat Seed Extract Bioflavonoids on the Antioxidant Status of Geese 633
Olena Danchenko, Lubov Zdorovtseva, Mykola Danchenko, Oleksandr Yakoviichuk, Tetiana Halko, Elena Sukharenko and Yulia Nicolaeva

Screening of Agricultural Raw Materials and Long-Term Storage Products to Identify Bacillary Contaminants 641
Olena Danylova, Marina Serdyuk, Liudmyla Pylypenko, Victor Pelykh, Inna Lopotan and Antonina Iegorova

Development of Formulation and Quality Assessment of Fast-Cooking Grain Composition for Pregnant Women 655
Nadya Dzyuba, Liubov Telezhenko, Maryana Kashkano and Oksana Maksymets

Innovative Technology of the Scoured Core of the Sunflower Seeds After Oil Expression for the Bread Quality Increasing 665
Victoria Evlash, Lydia Tovma, Iryna Tsykhanovska and Nonna Gaprindashvili

Effect of Living Mulch on Chlorophyll Index, Leaf Moisture Content and Leaf Area of Sweet Cherry (*Prunus avium* L.) 681
Tatyana Gerasko, Lyudmila Velcheva, Lyudmila Todorova, Lyubov Pokoptseva and Iryna Ivanova

Modification of Modeling Method of Toxic Dystrophy of Liver in Rats 689
Viktoriya Gryshchenko, Olena Danchenko and Viktoriya Musiychuk

Technological Properties of Winter Wheat Grain Depending on the Ecological and Geographical Origin of a Variety and Weather Conditions 699
Hrygoriy Hospodarenko, Olena Cherno, Ihor Prokopchuk and Marina Serdyuk

Multicriteria Optimization of Quality Indicators of Sweet Cherry Fruits of Ukrainian Selection During Freezing and Storage 707
Iryna Ivanova, Iryna Kryvonos, Liudmila Shleina, Galina Taranenko and Tatyana Gerasko

Effect of Preparations Methyure (6-Methyl-2-Mercapto-4-Hydroxypyrimidine) on Corn (*Zea Mays* L.) Biological Productivity Under Saline Soil Conditions 719
Maksym Kolesnikov, Yuliia Paschenko, Halyna Ninova, Maryna Kapinos and Anastasiia Kolesnikova

Sweet Ices with High Nutritional Value 729
Juliya Kozonova, Victoria Stepanova, Alla Salavelis and Alina Kulyk

Nitrogen in Soil Profile and Fruits in the Intensive Apple Cultivation Technology 737
Tetiana Maliuk, Natalia Pcholkina, Liliia Kozlova and Oksana Yeremenko

Technological Indices of Spring Wheat Grain Depending on the Nitrogen Supply 753
Larysa Novak, Vitalii Liubych, Serhii Poltoretskyi and Mykola Andrushchenko

Use of Alternative Types of Fuel for Grain Drying 763
Nina Osokina, Hennadii Tkachenko, Yana Yevchuk and Olena Hryhorenko

Effect of Seed Sowing Period on Antioxidant Protection of Basil (*Ocimum basilicum* L.) Under Greenhouse Conditions 769
Olesia Priss, Iryna Korotka, Galina Simakhina, Victoria Koliadenco and Tatiana Kolisnychenko

Determining the Risks of the Production Environment of an Agricultural Enterprise 777
Yurii Rohach, Oleh Yatsukh and Mykhailo Zoria

Development of Emulsion Sauce Technology for Preventive Nutrition 785
Lyubov Telezhenko, Gennadiy Diduch, Svitlana Kolesnichenko and Valentina Zhukova

The Influence of AKM Growth Regulator on Photosynthetic Activity of Oilseed Flax Plants in the Conditions of Insufficient Humidification of the Southern Steppe of Ukraine 793
Oksana Yeremenko, Svitlana Kalenska, Lyubov Pokoptseva and Liudmyla Todorova

Investigation of the Grinding Mode of the Enriched Wheat Products in the Rolling Mill 1-Grinding System of the Milling Mill of Wheat Grinding 807
Olena Yeremeeva, Yevgen Kharchenko, Hennadii Tkachenko, Iryna Shapoval and Olena Hryhorenko

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Corresponding Author	Family Name	**Milko**
	Particle	
	Given Name	**Dmytro**
	Prefix	
	Suffix	
	Role	
	Division	
	Organization	Tavria State Agrotechnological University
	Address	Melitopol, 72310, Ukraine
	Email	dmitro.milko@tsatu.edu.ua
	ORCID	http://orcid.org/0000-0002-0991-1930
Author	Family Name	**Bratishko**
	Particle	
	Given Name	**Viacheslav**
	Prefix	
	Suffix	
	Role	
	Division	
	Organization	National University of Life and Environmental Science of Ukraine
	Address	Kiev, 03041, Ukraine
	Email	vbratishko@nubip.edu.ua
	ORCID	http://orcid.org/0000-0001-8003-5016
Author	Family Name	**Kuzmenko**
	Particle	
	Given Name	**Volodymyr**
	Prefix	
	Suffix	
	Role	
	Division	
	Organization	National Scientific Centre "Institute for Agricultural Engineering"
	Address	Hlevakha, 08631, Ukraine
	Email	vfkuzmenko@ukr.net
	ORCID	http://orcid.org/0000-0002-3474-939X
Author	Family Name	**Kholodiuk**
	Particle	

Given Name	**Oleksandr**
Prefix	
Suffix	
Role	
Division	
Organization	Vinnytsia National Agrarian University
Address	Vinnytsia, 21008, Ukraine
Email	holodyk@vsau.vin.ua
ORCID	http://orcid.org/0000-0002-4161-6712

Abstract

The article presents the main theoretical aspects that describe the influence of the design parameters of the press chamber on the qualitative indices of plant materials compaction process in a wedge-shaped canal. The article analyzes the structure of the output monolith in terms of density in layers located at different heights, which allows making predictions about the further use of the resulting blocks of plant raw materials for long-term storage. Also article presents the structural scheme of the device designed to seal the plant material. Thanks to the proposed theoretical approach, it is possible to evaluate processes occurring during compaction. The article demonstrates that qualitative indicators of plant material compaction significantly affect the preservation of nutrients in the process of their storage. With insufficient sealing between the particles, there is an excessive amount of air that allows the development of pathogenic microflora. The next step is to damage and disintegrate the nutrients of feed raw materials. In the case of excessive sealing, the destruction of plant cells will occur, which is also a negative consequence. The mathematical description of the process of plant material compaction with a solution of dependencies is given. Mathematical modeling allowed to give a description of the interaction of plant materials with the surfaces of the sealing chamber and internal interactions between the particles of the plant material itself. Taking into account, the above-mentioned parameters, it is possible to more accurately plan the design of presses for certain plant materials taking into account their physical and mechanical properties.

Keywords (separated by '-')

Haylage - Plant material - Compacting - Sealing

Theoretical Aspects of Plant Material Sealing in a Wedge-Shaped Canal

Dmytro Milko, Viacheslav Bratishko, Volodymyr Kuzmenko and Oleksandr Kholodiuk

1 Introduction

The problem of nutrients preservation is very relevant at the present stage. In particular, it concerns the storage of haylage components in the diet at the autumn–winter period.

However, this problem can be solved by creating the latest sealing technology and equipment for its implementation. The development of technologies for planting raw materials in post-Soviet countries is carried out from 60 to 70 years.

The project examines the process of sealing plant stem materials in a wedge-shaped canal analyzes the density of the monolith in the height of the layer, which allows us to draw conclusions on further improvement of the technological process in relation to increasing the stored nutrients amount in the continuation of the conservation period.

D. Milko (✉)
Tavria State Agrotechnological University, Melitopol 72310, Ukraine
e-mail: dmitro.milko@tsatu.edu.ua

V. Bratishko
National University of Life and Environmental Science of Ukraine, Kiev 03041, Ukraine
e-mail: vbratishko@nubip.edu.ua

V. Kuzmenko
National Scientific Centre “Institute for Agricultural Engineering”, Hlevakha 08631, Ukraine
e-mail: vfkuzmenko@ukr.net

O. Kholodiuk
Vinnytsia National Agrarian University, Vinnytsia 21008, Ukraine
e-mail: holodyk@vsau.vin.ua

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2 Problem Statement

We propose a mathematical model describing the effect of hydrostatic stresses and components of shear viscoelastic deformations on the output density of a plant monolith after passing the rectilinear and inclined sections.

We also want to emphasize that for constructing a mathematical model we used the Kelvin–Voigt model and the generalized Hooke's law. On the other hand, it should be noted that the application of sealing technology in the wedge-shaped canal is an intermediate chain in creating a new energy-efficient sealing technology, which should take into account the physical and mechanical properties of plant stem materials. Exactly, the same research was already done by Ashour [1], who presented the results of compression tests performed on wheat and barley straw bales laid both flat and on-edge and found that wheat bales are stiffer than barley bales. Compression tests were performed by Zhang [2] and Brojan and Clouston [3] on flat and on-edge straw bales and they found a nonlinear stress–strain behavior. Four stages for straw bales compression were identified and an explanation for the mechanical behavior of bales laid flat was proposed by Zhang [2]. Zhang also performed a cyclic test in which a straw bale was subjected to three complete loading and unloading cycles, although neither the maximum stress on the bale nor the maximum bale deformation was kept constant from cycle to cycle.

Attempts to establish accordance between the required density of vegetative raw materials when placed on storage and the quality of nutrients preservation did not lead to positive results due to insufficient consideration of the physical and mechanical properties of plant material.

3 Solution

Considering the fact that the study of vegetative raw materials sealing with high humidity is rather specific due, is primarily, to the need to maintain initial humidity in the range of 65–75%, it is necessary to create a mathematical model that would allow to take into account the efforts that arise in particles of plant material. It will allow to manage the process of compaction and release the moisture contained in plant raw materials that ensure the silage process.

In many tasks related to the analysis of the interaction of working bodies and any deformers with materials and environments, it is necessary to use physical equations of stress–strain relations. In this case, such a connection may be manifested in the form of a significant influence of elastic, viscous, and plastic properties [4]. The fundamental laws and physical equations of the relationship of stresses with deformations (deformation rates) are used for the formalization of materials and environments in the form of models with a significant manifestation of certain types of these properties With complex types of properties influence, in particular, when all three properties appear in equal, the models of the connection of stresses with defor-

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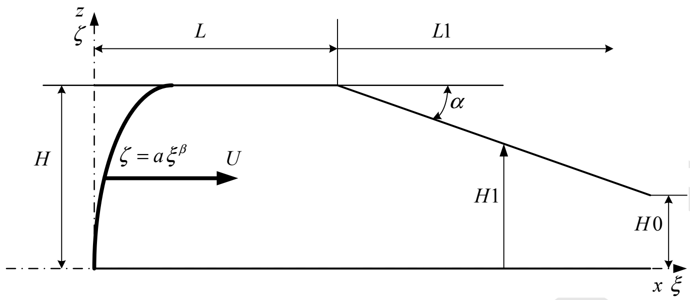

Fig. 1 Calculation scheme of the process of compaction of plant raw materials in the press with wedge-shaped canal. H, $H1$, $H0$—respectively, the height of the layer on a straight line, in the wedge-shaped section and at the exit from the press of the previous seal, m; L, $L1$—respectively, the length of the rectilinear and wedge-shaped press, m; α—tilt angle of the upper wall of the sealing chamber, rad.; U—speed of the piston, mm/s; ζ, ξ—coordinates of the surface of the press

mations (strain rates) are constructed for some cases, that is, for normal or landslide deformations only.

The calculation scheme of the press with a wedge-shaped canal is shown in Fig. 1.

Unfortunately, such a representation of a piston shape in the curvilinear surface form does not allow further integrating the biharmonic potential functions, so we will simplify the shape of the piston to a flat surface.

For calculation of material density, it is necessary to consider two stages of consolidation. The first stage is a seal in a rectilinear section of the press and the second stage is direct sealing in the wedge-shaped section of the press.

The sealing of the material at the end of the rectilinear part of the press can be determined by the dependence

$$\rho = \rho_0 + b \ln\left[\sqrt{\sigma_m^2}(1 + \tau_{xz})\right], \tag{1}$$

where

$\sigma_m = \frac{\sigma_x + \sigma_z}{3}$	hydrostatic stress;
ρ_0	initial material density;
b	an empirical coefficient, determined for a particular material in conditions of uneven compression;
$\sigma_x, \sigma_z, \tau_{xz}$	components of normal stresses;

$$\sigma_x = -\frac{2e^{\frac{Gt}{\mu}}\mu((-5 + 7\nu)\dot{\varepsilon}_x - 2(-2 + \nu)(\dot{\varepsilon}_y + \dot{\varepsilon}_z))}{9(-1 + \nu)}; \tag{2}$$

$$\sigma_z = \frac{2e^{\frac{Gt}{\mu}}\mu(2(-2 + \nu)\dot{\varepsilon}_x + 2(-2 + \nu)\dot{\varepsilon}_y + (5 - 7\nu)\dot{\varepsilon}_z)}{9(-1 + \nu)}; \tag{3}$$

$$\tau_{xz} = 2e^{\frac{Gt}{\mu}} \mu \dot{\gamma}_{xz}. \quad (4)$$

where

$\dot{\varepsilon}_x$ $\dot{\varepsilon}_z$, $\dot{\gamma}_{zx}$	shear strain rates of the material;
μ	module of material viscosity;
G	modulus of vegetation shift;
ν	Poisson's coefficient.

$$\dot{\varepsilon}_x = \frac{\partial u}{\partial x}; \dot{\varepsilon}_z = \frac{\partial w}{\partial z}; \dot{\gamma}_{zx} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}. \quad (5)$$

u, w projection of the speed of the press on the axis of the coordinates;

$$u = \Phi_x - \frac{1}{4(1-\nu)} \frac{\partial}{\partial x}(x\Phi_x + z\Phi_z); \quad (6)$$

$$w = \Phi_z - \frac{1}{4(1-\nu)} \frac{\partial}{\partial z}(x\Phi_x + z\Phi_z). \quad (7)$$

where

Φ_x, Φ_z the Papenkich-Neuer function on the x- and z-axes;

$$\Phi_x = \int_0^H \frac{ku_{x0}(H + z + \delta - \zeta)}{(H + z + \delta - \zeta)^2 + (L + x + \delta - \xi)^2} d\zeta;$$

$$\Phi_z = \int_0^{\xi \max} \frac{ku_{z0}(H + z + \delta - \zeta)}{(H + z + \delta - \zeta)^2 + (L + x + \delta - \xi)^2} d\xi. \quad (8)$$

After integrating the reduced functions, we obtain a solution

$$\Phi_x = \frac{aHkU(-H^2 + H(ax - z) + 2axz)}{(H^2 + x^2 + 2Hz + z^2)(H^2 - 2aHx + a^2(x^2 + z^2))};$$

$$\Phi_z = \frac{aHkU(-a(x - z)(x + z) + H(x + az))}{\sqrt{1 + a^2}(H^2 + x^2 + 2Hz + z^2)(H^2 - 2aHx + a^2(x^2 + z^2))}. \quad (9)$$

To calculate the final density of plant material at the exit from the wedge-shaped canal, it is necessary to repeat the same operations as for a straight line plot and substitute them in Eq. (10)

$$\rho L1 = \rho_0 + b' \ln[\sqrt{\sigma_{mL1}^2}(1 + \tau_{xzL1})]; \quad (10)$$

where $\sigma_{mL1} = \frac{\sigma_{xL1} + \sigma_{zL1}}{3}$, hydrostatic stress.

478803_1_En_15_Chapter ✓ TYPESET DISK LE ✓ CP Disp.:30/5/2019 Pages: 144 Layout: T1-Standard

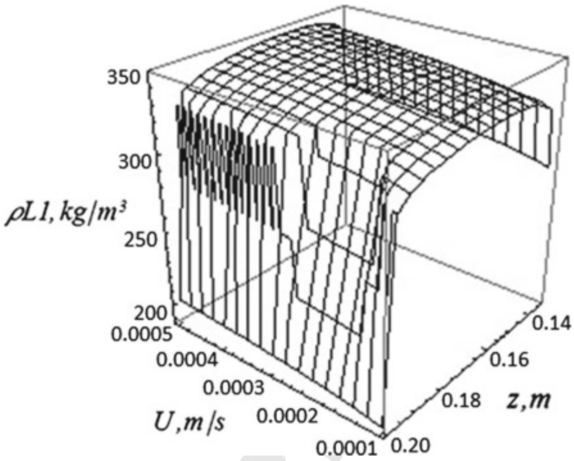

Fig. 2 Graphic representation of the density distribution by height and speed of the sealing press U

In a similar way, the stresses are calculated for the narrowing area $L1$ of the wedge-shaped canal.

Graphical interpretation of the calculation of plant raw material density at the exit from the wedge-shaped canal press is presented in Fig. 2.

The presented graphic dependencies are constructed according to the following initial conditions: $\alpha = \pi/4$, $\rho_0 = 200$ kg/m^3, $H = 0.5$ m, $L = 1$ m, $U = 0.0003$ m/s.

4 Conclusion

Analyzing the foregoing, we should note the uneven distribution of the compacted material output density at the layer layout height. Since this fact will affect the subsequent distribution of air in the material mass, it is necessary to align the density in the subsequent layout process before the sealing operation.

In the case of storage of compacted plant material in the wedge-shaped canal, there will be problems associated with excessive sealing in the upper layers of plant material and with insufficient sealing in the lower layers. However, the overall density of the package will be within the recommended range. In turn, in the upper layers, there will be processes of destruction of shells of cells with the flow of juice of plants. And in the lower layers, there will be layers with excessive air, which will oxidize crushed plants and juice that stands out from the upper layers. In the pile, all this will reduce the nutritional value of feed materials and reduce the taste appetite of the feed. The consequence of this will be the reluctance of animals to eat food, a decrease in diet, reduced incline, increased cases of animal diseases, deterioration of the sanitary and epidemiological situation in the farm in general.

In general, poor quality sealing of plant material leads not only to the loss of nutrient elements of feed raw materials, but also to many negative economic consequences. Therefore, the uniformity of sealing of plant material for storage is very important at the present stage of livestock development. This also applies to the packing of haymaking in rolls, where the density in the inner part is less than the outside density. Also, these processes can be observed when creating rectangular bales. Very often this occurs when plant raw materials are loading in the trench storage.

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