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INVESTIGATION OF INTENSIVE WEAR ZONES OF AN OIL PRESS SCREW DURING OILSEED PROCESSING



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Abstract:
The article presents a computational and experimental study of the wear of an oil press screw during the processing of oilseed raw materials. The study aimed to determine the most heavily loaded zones of the screw by comparing an engineering calculation model with experimental data. The calculation model included a linear pressure distribution along the screw, Coulomb's law to estimate friction, and Archard's equation to predict linear wear. Experimental verification was conducted by measuring changes in the geometric parameters of the screw flights across three screw zones after operation. The calculated annual wear in zones I, II, and III was 0.166, 0.243, and 0.318 mm/year, respectively, while the experimental values were 0.178, 0.260, and 0.348 mm/year, respectively. The deviation between the calculated and experimental data was within 7.2-9.4%, which confirms the applicability of the proposed model for preliminary wear assessment. It was established that the maximum wear is localized in zone III, corresponding to the final compression and material discharge section. The obtained results justify the need for local strengthening or the application of a wear-resistant coating to the most heavily loaded screw sections. From a practical standpoint, the proposed approach can be used in the reliability management system of an oil press to plan periodic inspections, identify priority maintenance areas, and select economically justified zones for screw restoration or strengthening.

Key words: screw wear, oil press, Archard model, oilseed processing, three-dimensional visualization

INTRODUCTION

The reliability and wear resistance of the working parts of screw-type oil presses are important factors determining the stability of the pressing process, oil yield, energy consumption, and equipment service life. During mechanical pressing, the screw simultaneously transports the raw material, compacts it, generates pressure in the pressing chamber, and promotes oil separation. Therefore, wear of the screw surface leads to changes in flight geometry, disruption of the pressing regime, reduced oil recovery, and shortened service life of the component [1, 2, 3].

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Wear of the pressing screw results from a combination of structural, technological, and tribological factors. These include pressing pressure, contact friction, the physical and mechanical properties of the raw material, moisture content, degree of grinding, screw rotational speed, flight geometry, and resistance to the discharge of the oil cake mass. Uneven pressure distribution along the screw length causes local overloads, increased shear stresses, and accelerated destruction of the working surface [4, 5, 6]. Disturbance of stable material movement, reverse flow of the oil cake, and increased axial resistance further intensify damage to the most heavily loaded sections [7, 8, 9].

Modern studies on screw pressing primarily focus on increasing oil yield, productivity, and energy efficiency by optimizing rotational speed, die clearance, the geometry of the pressing unit, the design of the pressing chamber, and temperature – force conditions [10, 11]. Computational and experimental studies of the stress-strain state of screw mechanisms show that maximum stresses and damage are usually concentrated in compression and discharge zones, flight junction areas, and sections with abrupt changes in contact loads [12, 13, 14]. Finite element analysis, failure assessment, automated monitoring, and equipment reliability modeling methods are used to identify such zones [15, 16, 17].

At the same time, most of the above approaches are primarily focused on evaluating equipment productivity, strength, reliability, or technological efficiency. Less attention has been paid to the quantitative description of zonal wear on the screw working surface and its relationship to the distribution of pressure, friction, and relative sliding of the material [18, 19, 20]. Studies of small-scale presses, oil drainage channels, pressure regulation mechanisms, and pressing modes confirm that pressing efficiency is determined not only by the magnitude of pressure, but also by the coordination of screw design, resistance to oil cake discharge, temperature, raw material feed, and kinematic regime [21, 22, 23, 24, 25, 26]. However, the spatial distribution of wear across individual zones of the oil press screw has not been sufficiently addressed in these studies.

Materials science and tribological studies of the working parts of agricultural machinery show that, in contact with plant raw materials, mineral impurities, and pressing products, abrasive, adhesive, and fatigue wear mechanisms predominate [27, 28, 29]. Increasing the service life of such parts is associated with the use of wear-resistant steels, heat treatment, chemical heat treatment, surface strengthening, hardfacing, and protective coatings [30, 31, 32]. However, the effectiveness of these solutions should be evaluated with consideration of the actual load distribution along the screw length, since coating application or local strengthening is most appropriate in the zones of maximum pressure and friction [33, 34, 35].

Thus, despite the significant number of studies devoted to the optimization of screw pressing, the modeling of the technological process, the assessment of equipment strength, and the application of wear-resistant materials, the task of quantitatively determining the zones of intensive wear of an oil press screw remains insufficiently studied. In particular, the relationship among pressure distribution, changes in oil yield, and the localization of hazardous wear zones on the pressing screw has not been fully established. Therefore, an engineering model is required that enables not only qualitative indication of wear but also quantitative determination of the screw sections where the combination of pressure and friction poses the highest risk of accelerated destruction of the working surface.

The scientific problem of this study is the need for a justified determination of the most heavily loaded zones of the oil press screw, where the combination of pressure, friction, and relative sliding leads to accelerated loss of the flights' geometric accuracy. Solving this problem is important for predicting the service life of the component, selecting priority areas for inspection, restoration, local strengthening, and application of wear-resistant coatings.

The study aims to determine the zones of intensive wear on an oil press screw during the processing of oilseed raw materials by comparing a calculation model with experimental measurements. The scientific novelty of the work lies in the combination of an engineering calculation of pressure distribution, friction assessment, linear wear calculation using Archard's model, and experimental verification of changes in flight geometry in three screw zones. This approach makes it possible not only to establish the non-

uniformity of wear but also to quantitatively identify the sections where the risk of accelerated destruction of the working surface is the highest.

The practical significance of the study lies in the potential to use the results obtained to manage the reliability and service life of oil press equipment. The proposed wear zoning enables a shift from uniform maintenance of the entire component to risk-oriented maintenance, in which condition monitoring, restoration, and coating application are carried out primarily on the most heavily loaded sections of the screw.

LITERATURE REVIEW

International review studies on the continuous mechanical expression of oil from seeds show that the process is governed by the combined influence of raw material properties, moisture content, temperature, material residence time, the geometry of the pressing unit, and resistance to cake discharge [36]. These observations confirm the need to consider screw wear not in isolation but in relation to the technological parameters of the pressing process.

In the study by Chapuis et al. [37], devoted to screw pressing of the oilseed crop Jatropha curcas, it was established that the efficiency of oil separation and energy consumption depends on raw material preparation and press settings. The authors demonstrated that the energy consumption of the process depends on the pressing regime and the degree of oil extraction, which indicates the need for rational selection of pressure in the working zone of the screw.

Bogaert et al. [38] performed an experimental characterization of the mechanical pressing of oilseeds using an instrumented pilot-scale screw press. Functional sections of feeding, compression, mixing, and relaxation were identified along the screw. Additionally, it was shown that the compression zones are accompanied by increased pressure, oil separation, and the formation of a dense press cake. These data provide an important basis for zoning the screw used in the present study into the sections of initial compaction, main pressing, and final compression.

For sunflower and safflower raw materials, it has been shown that the degree of grinding, screw rotational speed, pressure, and design of the pressing unit significantly affect oil yield, temperature, cake density, productivity, and energy consumption [1, 10, 11]. Subsequently, changes in the technological regime may simultaneously increase the efficiency of oil separation and intensify contact loads on the working surface of the screw.

Kovalyshyn and Tomyuk [39] established that the energy consumption during rapeseed pressing includes the energy required for material compaction, overcoming friction between the raw material, screw, and press cage, as well as the actual separation of oil. Indartono et al. [40] showed that increasing temperature and raw material feed rate may improve oil yield; however, excessive feeding increases the risk of clogging in the filtration section. These results confirm the need for a criterion-based assessment that accounts for not only oil yield but also the risk of overloading the working surface.

The tribological basis for calculating wear in the present study is Archard's model [41], which relates wear to load, sliding distance, and material hardness. For screw working elements interacting with abrasive plant material, this model can be used as an initial engineering approximation. In addition, numerical studies of screw conveyors show that wear and related parameters are sensitive to surface geometry, relative sliding, and local loading [42].

Moreover, Ivanov et al. [43] investigated the improvement in abrasive wear resistance of worn parts of production equipment by hardfacing with flux-cored wires containing reaction mixtures of boron carbide and metallic powders. The authors noted that conventional Fe-Cr-C hardfacing materials do not always provide sufficient resistance under high specific and cyclic loads, including during the restoration of screws. Their results confirm that increasing the service life of such parts should be associated not only with increasing hardness but also with the formation of a finer-grained structure containing refractory borides, carbides, and their solid solutions. This finding further strengthens the practical

justification for the use of wear-resistant coatings and local strengthening of the working surfaces of oil press screws.

Similar tribological results were reported by Bembenek et al. [28], who investigated the wear mechanism of mill beaters for coal grinding made of high-manganese cast steel. The authors showed that insufficient wear resistance of working elements is associated with chemical composition, structure, hardness, and the ability of the surface layer to undergo strengthening. These findings confirm the need to consider not only the external load but also the material of the working part, its hardness, and structural condition when predicting service life. In the present study, this approach is used to interpret screw wear in 40Kh steel and to justify the need for wear-resistant coatings or local strengthening.

Studies of a similar nature are presented in works devoted to assessing screw wear in specific working sections. El-Ashry and Tawfik [44] investigated the abrasive wear of a conical oil press screw during flaxseed oil expression and identified three zones: feeding, crushing, and pressing. According to the published data, after prolonged operation, the most pronounced wear occurred non-uniformly and was concentrated in the zone of intensive mechanical action on the raw material, while surface strengthening reduced the amount of wear. Ariani et al. [12] also showed that for an industrial palm oil screw press, the most critical section is the screw segment in contact with the pressure cone, where local loads and friction lead to the maximum wear rate.

Thus, the reviewed literature provides the basis for the present study's calculations: pressure distribution along the screw determines the contact load, friction determines the tangential stresses, and the combination of pressure and relative sliding affects the intensity of wear.

Furthermore, the analysis of studies on hardfacing and restoration of worn parts [43, 45], wear mechanisms of high-manganese steels [28], and zonal wear of screw working elements [12, 44] confirms that increasing the service life of such parts should be based on a combination of load assessment, experimental wear control, and justified selection of material or coating for the most heavily loaded zones. On this basis, the article applies an engineering approach that combines a pressure model, Coulomb's law, Archard's equation, an integral wear-hazard criterion, and experimental verification of wear distribution across zones.

The approaches reported in the literature also show that improving equipment reliability requires not only the selection of wear-resistant materials but also the identification of critical working zones, the planning of preventive inspections, and the reduction of repair costs. In this regard, the analytical and experimental identification of hazardous screw sections can be considered a decision-support tool for maintenance and service-life management of oil press equipment.

METHODOLOGY OF RESEARCH

The study was carried out as a comprehensive analytical–calculation and experimental assessment of screw wear. The object of the study was the working screw of a 6YL-80 screw oil press designed for processing safflower or sunflower raw material. The screw material was 40 Kh structural alloy steel with the following chemical composition (wt.%).%: C – 0.36-0.44; Cr – 0.80-1.10; Mn – 0.50-0.80; Si – 0.17-0.37; Ni – up to 0.30; Cu – up to 0.30; S – up to 0.035; P – up to 0.035; Fe – approximately 97. The design and technological parameters of the 6YL-80 screw oil press were used as the initial data. These parameters were applied both to the calculation-based validation of the proposed methodology and to the experimental assessment of wear distribution across the screw working surface zones.

The working length of the screw was conventionally divided into three equal zones: zone I – feeding and initial compaction; zone II – main pressing and intensive oil separation; zone III – excessive compaction and material discharge. The zoning scheme of the screw working section is shown in Figure 1.

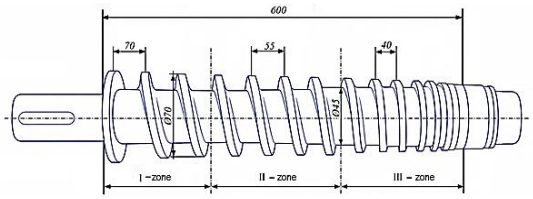


Fig. 1 Scheme of dividing the working length of the oil press screw into calculated wear zones
Alt text: *The screw working length is divided into three calculated wear zones. Zone I corresponds to feeding and initial compaction, zone II to main pressing and intensive oil separation, and zone III to excessive compaction and material discharge.*

In a first approximation, the pressure gradient along the screw is assumed to be linearly increasing:

$$P(x) = P_{min} + \left[\frac{P_{max} - P_{min}}{L}\right] x, \tag{1}$$

where:
P_{min} – minimum pressure at which oil separation begins, MPa;
P_{max} – maximum allowable pressing pressure, MPa;
L – working length of the screw, m;
x – longitudinal coordinate along the screw, m,
where:
$x = 0$ corresponds to the material feeding zone;
$x = L$ – corresponds to the outlet zone of the pressing chamber.
According to this relationship, at $x = 0$ the pressure equals P_{min}, while at $x = L$ it equals P_{max}. Consequently, the model reflects the gradual increase in pressure from the material-feeding zone to the outlet of the screw.
The assumption of a linearly increasing pressure distribution was adopted because the free volume between screw flights gradually decreases from the feeding zone to the outlet, which causes progressive compaction of the oilseed material. This assumption provides a transparent engineering approximation for dividing the screw into wear-risk zones. However, the real pressure curve may be nonlinear due to feed fluctuations, local cake blockage, temperature changes, moisture variation, and raw-material heterogeneity. Therefore, the model should be used for preliminary zoning and comparative assessment rather than for a detailed transient description of pressure inside the press chamber.
The minimum pressure P_{min} was determined as the sum of the material's structural resistance to compression, the additional pressure required to overcome friction, and the threshold pressure at which oil filtration begins. The maximum pressure P_{max} was limited by the seed kernel's critical compressive stress, accounting for the safety factor.
The tangential friction stress was estimated according to Coulomb's law:

$$\tau(x) = \mu P(x), \tag{2}$$

where:
$\mu = 0.30$ – is the coefficient of friction.
The friction coefficient $\mu = 0.30$ was adopted as an average engineering value for the contact between the 40 Kh steel screw surface and compressed oilseed cake under lubricated-abrasive conditions. This value was selected based on literature data for the friction of steel surfaces interacting with plant raw material [46] and preliminary operational observations of stable pressing without clogging. Since μ may vary depending on surface roughness, residual oil content, seed moisture, temperature, sliding velocity, and mineral impurities, a constant value was used in this study as an engineering assumption for comparative calculations. Refinement of the friction coefficient for other operating conditions requires special tribological tests; therefore, a sensitivity interval of 0.20-0.40 was additionally analysed in Figure 7.
Archard's equation in time-dependent form was used to calculate wear:

$$\check{h}(x) = kP(x)\,\upsilon_{rel}/H, \tag{3}$$

where:
$\check{h}(x)$ – is the linear wear rate, m/s;

k – the wear coefficient;
P(x) – the contact pressure at point x, Pa;
H – the hardness of the screw material, Pa;
υ_{rel} – the relative sliding velocity of the material layer along the screw surface, m/s.
To assess the risk of local wear, an integral criterion was introduced:

$$K_{wear}(x) = \mu P^2(x). \quad (4)$$

This criterion does not replace the physical calculation of wear but enables clear demonstration of the increased risk of wear as pressure and friction increase.
Archard's model was used because screw wear under the investigated conditions is governed mainly by normal load, sliding distance, and material hardness. The model is widely applied to abrasive and adhesive wear processes and is suitable for a preliminary comparative assessment of wear distribution on the screw working surface. Its use in this study is therefore limited to engineering zoning and comparison with experimental measurements rather than to a detailed description of all transient wear mechanisms.
The wear coefficient $k = 1.0 \cdot 10^{-8}$ was adopted based on literature data on Archard-based modelling of wear processes in metallic parts [47, 48] and corresponds to moderate abrasive-adhesive wear of a steel surface interacting with compressed plant material and solid impurities. For the 40 Kh steel screw operating during safflower seed processing, this value was used as an engineering approximation rather than as a universal constant. Safflower oil may partly act as a lubricant, whereas solid particles and mineral impurities may intensify abrasive wear of the working surface.
For clarity, the notation was unified throughout the manuscript as follows: P_{min} and P_{max} denote the minimum and maximum pressures, P(x) denotes local contact pressure, μ is the friction coefficient, k is the wear coefficient, H is material hardness, υ_{rel} is the relative sliding velocity, h is linear wear depth, and K_{wear} is the integral wear criterion.
For practical interpretation, the calculation and experimental assessment of wear were performed under a single-shift operating mode: 8 h/day and 250 working days per year, corresponding to an annual operating time of $T = 7.2 \cdot 10^6$ s. The maximum allowable wear depth was taken as 2.0 mm. This value was selected as a conventional engineering limit [assumed engineering threshold] at which changes in the geometry of the screw flights may already noticeably affect the clearance, transporting capacity, and stability of the pressing process. The core diameter of the screw varies along the working length and increases toward the final compression zone. For the calculation assessment, an average design value of the core diameter, d = 45 mm, was used. The adopted design and technological data of the calculated screw are presented in Table 1.

Table 1

Adopted structural and technological data of the calculated screw

Parameter	Symbol	Adopted Value
Working length of the screw	L	0.60 m
Outer flight diameter	D	70 mm
Core diameter (variable; average calculated value)	d	45 mm
Flight pitch by zones	s	70; 55; 40 mm
Pressing cross-sectional area	A	0.002 m²
Screw rotational speed	n	80 rpm
Relative sliding velocity	υ_{rel}	0.50 m/s
Friction coefficient	μ	0.30
Screw material	-	40 Kh steel
Material hardness	H	$2.02 \cdot 10^9$ Pa
Wear coefficient	k	$1.0 \cdot 10^{-8}$
Normal force	N	800 N
Minimum oil filtration pressure	ΔPmin	1.0 MPa

To compare the calculation model with operational data, an experimental assessment of screw wear was conducted across three zones of the working surface. Measurements were performed before the start of operation and after one year of screw service. The actual operating time was 2000 h, corresponding to a single-shift operating mode of 8 h/day for 250 working days.

A digital caliper with a resolution of 0.01 mm and a digital micrometer with a resolution of 0.001 mm were used to measure the geometrical parameters. Wear was determined by changes in the radial profile of the screw flights' working edge. Before measurements, the screw surface was cleaned of residues of the processed raw material, oil deposits, and contaminants.

Measurements were performed separately in three zones. In each zone, three control points were selected, evenly distributed along the length of the section. At each control point, at least three repeated measurements were performed, after which the average wear value was calculated. The measurements were carried out at an ambient temperature of (20±2)°C.

Measurement repeatability was assessed by calculating the standard deviation for each zone based on the repeated control measurements. This made it possible to evaluate the scatter of the experimental data and to compare it with the calculated deviation between the analytical model and operational measurements.

The wear value was determined as the difference between the initial and final values of the measured profile. The parameters of the experimental verification were consistent with the calculation section: the screw material was 40 Kh steel, the rotational speed was 80 rpm, and the raw material was safflower seed with a moisture content of 7-9%. This measurement procedure enabled comparison of the calculated wear values with the experimental data for each screw zone.

The measurement results were considered not only as an experimental verification of the calculation model but also as input data for the operational classification of screw zones according to risk level. The zones with the most wear were classified as priority areas for inspection, preventive repair, and local strengthening, which correspond to the principles of reliability management for production equipment.

RESULTS OF RESEARCH

The minimum pressure must be sufficient to overcome all resistances occurring at the initial stage of the pressing process:

$$P_{min} = \sigma_{comp} + \mu N/A + \Delta P_{min}. \quad (5)$$

At σ_{comp} = 6.0 MPa, μ = 0.30, N = 800 N, A = 0.002 m² and ΔP_{min} = 1.0 MPa, the following values were obtained: μN/A = 0.12 MPa; P_{min} = 6.0 + 0.12 + 1.0 = 7.12 MPa. This value corresponds to the onset of stable oil separation and the transition from simple compaction to effective pressing.

The following condition limited the maximum pressure:

$$P_{max} = (1 - \beta)\sigma_{cr}. \quad (6)$$

At the critical compressive stress of the seed kernel, σ_{cr} = 22.0 MPa, and the safety factor β = 0.10, the value P_{max} = 19.8 MPa was obtained. Thus, in the calculation example, the rational operating pressure range is 7.12-19.8 MPa. With further pressure increases, a decrease in technological efficiency is expected: oil yield increases only slightly, whereas the load and wear risks increase.

The average pressures in the three zones were determined using the linear pressure distribution model: P_I = 9.23 MPa, P_{II} = 13.46 MPa, P_{III} = 17.69 MPa. The exponential dependence $M(P) = M_0(1 - e^{-\alpha P})$ was used to describe oil yield qualitatively: in zone I, oil separation is unstable; in zone II, the main share of oil yield is formed; and in zone III, the process approaches saturation (Figure 2). This means that the final pressing section operates under maximum mechanical loading with a limited increase in useful oil yield.

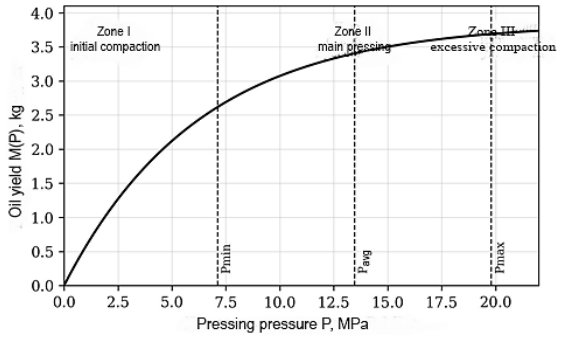


Fig. 2 Dependence of oil yield on pressing pressure and boundaries of screw zones
Alt text: *Curve showing oil yield increasing with pressing pressure and approaching saturation in zone III.*

The results of the pressure calculations, estimated oil yield, and the nature of wear in the screw zones are presented in Table 2.

Table 2
Calculation of pressure, oil yield, and wear mechanism by zones

Zone	Screw section	Pressure range	Average pressure, MPa	Approximate oil yield	Predominant wear mechanism
I	Feeding and initial compaction	0 ≤ P < Pmin	9.23	about 2.6 kg	abrasive wear, low intensity
II	Main pressing	Pmin ≤ P ≤ Pmax	13.46	about 3.4 kg	mixed abrasive-adhesive wear
III	Final compression and material discharge	P > Pmax/around Pmax	17.69	about 3.6-3.8 kg	intensive abrasive-adhesive wear

As shown in Table 2, the average pressure increases during the transition from zone I to zone III, the nature of wear changes, and the load on the screw working surface increases.
Using Archard's equation, the following values of linear wear rate were obtained: for zone I – $2.31 \cdot 10^{-11}$ m/s, for zone II – $3.37 \cdot 10^{-11}$ m/s, for zone III – $4.42 \cdot 10^{-11}$ m/s. With an annual operating time of $7.2 \cdot 10^{6}$ s, the annual wear is 0.166, 0.243, and 0.318 mm/year, respectively. In the critical section near the die, where the pressure may approach P_{max} = 19.8 MPa, the calculated wear rate is $4.95 \cdot 10^{-11}$ m/s, and the annual wear is 0.356 mm/year.
If the allowable wear depth is set at 2.0 mm, the calculated service life by zone is approximately 12.0 years for zone I, 8.2 years for zone II, and 6.3 years for Zone III. For the most heavily loaded limiting section near the die, the service life decreases to 5.6 years. Therefore, the final screw flights and the outlet section of the screw should be considered the priority zone for inspection, restoration, or application of a protective coating. The calculated annual wear values and the predicted screw service life for individual zones are presented in Table 3. The data in Table 3 show that the greatest annual wear occurs in zone III and in the limiting section near the die, where the screw service life is minimal.

Table 3
Calculation of annual wear and service life by zones

Indicator	Zone I	Zone II	Zone III	Limiting section near the die
Average/limiting pressure, MPa	9.23	13.46	17.69	19.80
Wear rate, m/s	$2.31 \cdot 10^{-11}$	$3.37 \cdot 10^{-11}$	$4.42 \cdot 10^{-11}$	$4.95 \cdot 10^{-11}$
Annual wear, mm/year	0.166	0.242	0.318	0.356
Service life at h_{allow} = 2 mm, years	12.0	8.3	6.3	5.6
Relative wear according to Archard's model	1.00	1.46	1.92	2.14

The integral wear criterion $K_{wear} = \mu P^2$ shows a sharper increase in risk than the linear pressure-based assessment. For zones I, II, and III, the obtained (K) values were: 25.56; 54.36 and 93.87 arbitrary units. When normalized to the first zone, the ratios were 1:2.13:3.67. This means that the risk of wear in the final pressing zone is approximately 3.67 times higher than in the initial compaction zone. The obtained result has important practical significance. If wear is assessed only as a linear function of pressure, zone III exceeds zone I by approximately 1.92 times. However, when pressure and friction are considered simultaneously through $K_{wear} = \mu P^2$, the increase in wear risk becomes much more pronounced. Therefore, for engineering decisions regarding local strengthening or coating application, the criterion-based approach is more informative. From the maintenance perspective, the obtained values make it possible to define different priority levels for inspection: zone I requires standard periodic inspection, zone II requires enhanced monitoring when the pressing regime changes, while zone III and the section near the die should be considered critical elements that determine the screw service life and its restoration schedule.

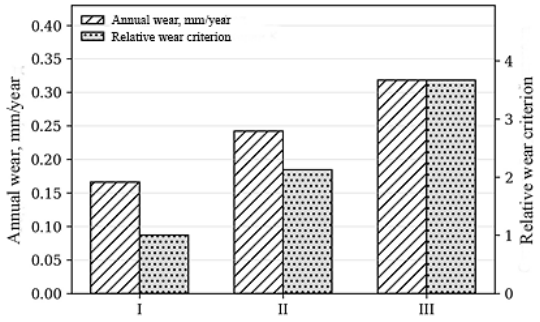


Fig. 3 Comparison of annual wear and the relative integral criterion by screw zones
Alt text: *Bar chart comparing annual wear and relative wear criterion, with the highest values in zone III.*

Experimental examination of the laboratory oil press screw after operation revealed non-uniform wear along the length of the working section. The most pronounced signs of wear were recorded in the final compression zone, whereas changes in the geometry of the screw flights were minimal in the initial compaction zone. Figure 4 shows the appearance of the screw before and after operation.

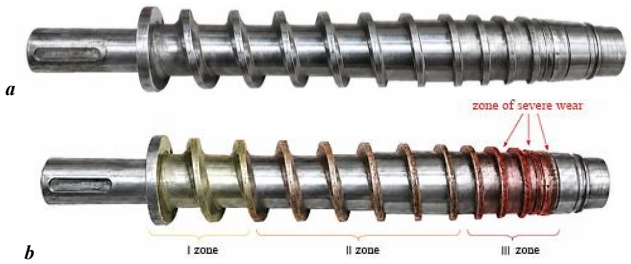


Fig. 4 Screw before (a) and after (b) operation
Alt text: *Screw before and after operation, with severe wear concentrated in the final compression zone. Table 4 presents the results of experimental screw wear by zones.*

Table 4
Results of experimental screw wear by zones

Zone	Screw section	h_1, mm	h_2, mm	h_3, mm	h_{avg}, mm	h_{annual}, mm/year
I	Feeding and initial compaction	0.168	0.178	0.188	0.178	0.178
II	Main pressing	0.248	0.260	0.272	0.260	0.260
III	Final compression and material discharge	0.328	0.348	0.366	0.348	0.348

The experimental values show a consistent increase in wear from the initial compaction zone to the final compression zone. During the screw operation period, the average wear depth increased from 0.178 mm in zone I to 0.348 mm in zone III. The greatest wear was observed in the final compression zone, where it was approximately twice that in the initial compaction zone. Therefore, the calculated conclusion of the experimental pattern confirms that maximum wear is localized in the outlet part of the screw. The repeatability of the experimental assessment was additionally evaluated from the three control measurements in each zone. The calculated standard deviations were 0.010 mm for zone I, 0.012 mm for zone II, and 0.019 mm for zone III. Taking into account the instrument resolutions and repeated measurements, the total experimental uncertainty of the wear assessment was assumed not to exceed ±0.02 mm. Table 5 presents the results of the comparison between the calculated and experimental screw wear values by zone.

Table 5

Comparison of calculated and experimental wear values by zones

Zone	Calculated wear, mm/year	Experimental wear, mm/year	Absolute deviation, mm/year	Relative deviation, %	Calculated relative wear	Experimental relative wear
I	0.166	0.178	0.012	7.2	1.00	1.00
II	0.242	0.260	0.018	7.4	1.46	1.46
III	0.318	0.348	0.03	9.4	1.92	1.96

Comparison of the calculated and experimental data shows consistency between the results. In all three zones, the pattern of wear variation is consistent, while the relative deviation between the calculation and the experiment ranges from 7.2% to 9.4%. This confirms the applicability of the engineering model used for the preliminary assessment of screw service life. The obtained discrepancy can be considered acceptable for an engineering model, since the calculation based on Archard's equation takes into account average values of pressure, hardness, and sliding velocity, but does not fully reflect the influence of mineral impurities in the raw material, local pressure fluctuations, temperature, and non-uniform roughness of the working surface. Figure 5 compares the calculated and experimental annual wear values by screw zone.

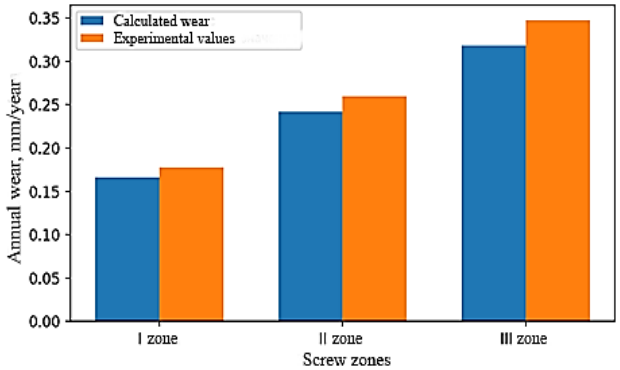


Fig. 5 Comparison of calculated and experimental annual wear by screw zones

Alt text: *Bar chart comparing calculated and experimental annual wear values for three screw zones.*

3D visualization and practical interpretation of the results using Statistica 10.

For the visual presentation of the results, 3D response surfaces were constructed in Statistica 10 to illustrate the effects of pressing pressure, relative sliding velocity, and coefficient of friction on wear intensity. The visualization was used as an auxiliary tool for interpreting the calculated and experimental data; the main emphasis was placed on identifying critical zones and determining their practical significance for screw operation.

The 3D surface of annual wear (Figure 6) confirms that an increase in pressure and relative sliding velocity leads to a monotonic increase in annual wear depth (h_{year}).

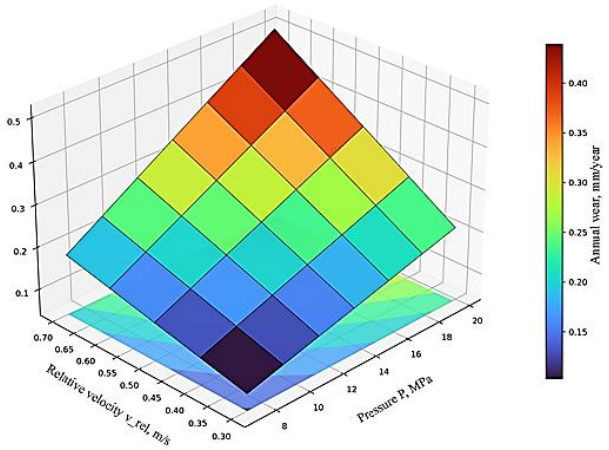


Fig. 6 3D dependence of annual screw wear on pressing pressure and relative sliding velocity
Alt text: *3D surface showing annual screw wear increasing with pressing pressure and sliding velocity.*

The most unfavorable region corresponds to pressures of 17.69-19.80 MPa and velocities of 0.60-0.70 m/s, i.e., to the operating regime characteristic of zone III of the screw. From a practical standpoint, this indicates the need to stabilize the raw material feed, prevent excessive resistance to press-cake discharge, and control the kinematic operating conditions.
The surface of the integral criterion $K_{wear} = \mu P^2$ (Figure 7) indicates that increasing the coefficient of friction is especially critical under high-pressure conditions.

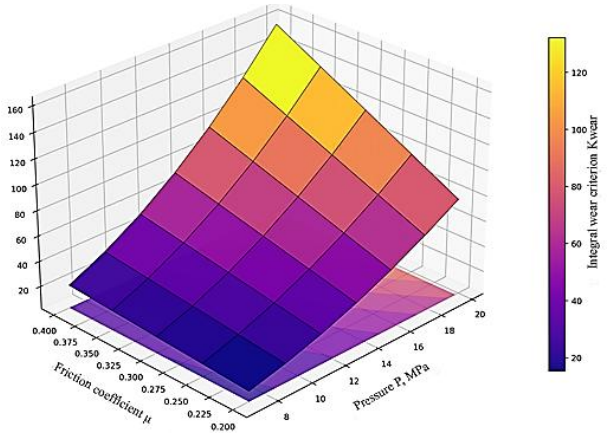


Fig. 7 3D dependence of the integral wear criterion on pressing pressure and friction coefficient
Alt text: *3D surface showing the integral wear criterion increasing with pressure and friction coefficient.*

When μ increases from 0.20 to 0.40, the criterion value increases by nearly twofold, and as pressure rises, the wear risk intensifies further due to the quadratic dependence on P.
From a practical point of view, 3D visualization is used as a tool for engineering interpretation rather than as an independent software component of the study. It enables identification of the operating regimes under which the final screw flights and the section near the die require priority inspection, restoration, or application of a wear-resistant coating.
Experimental 3D visualization of wear distribution by zones and operating time (Figure 8) confirms the calculated trend: wear depth increases from zone I to zone III and with increasing screw operating time. The maximum values are concentrated in the final compression zone, which is consistent with the results of the calculations and measurements.

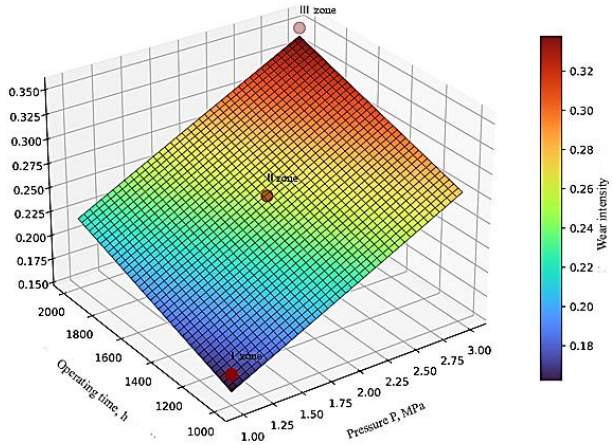


Fig. 8 3D visualization of the experimental wear distribution by screw zones
Alt text: *3D surface showing experimental wear depth increasing from zone I to zone III over operating time.*

Thus, 3D visualization is not treated as a standalone software block, but rather serves as a tool for the engineering interpretation of the results. It helps justify a risk-oriented maintenance plan, identify critical diagnostic zones, and select areas for local strengthening without overloading the text with a description of software procedures.

DISCUSSION

Comparison of the calculated and experimental data shows that the proposed model correctly reflects the general pattern of wear distribution along the screw length. In the calculation part, the annual wear in zones I, II, and III was 0.166, 0.243, and 0.318 mm/year, respectively, whereas the experimental assessment yielded close values of 0.178, 0.260, and 0.348 mm/year. In all cases, the same regularity was observed: as the transition from the initial compaction zone to the final compression zone occurs, wear increases monotonically. The deviation between the calculation and the experimental assessment did not exceed 10%, confirming the applicability of Archard's model for preliminary engineering prediction of wear. At the same time, the slight excess of the experimental values over the calculated ones may be linked with the additional influence of temperature, feedstock heterogeneity, and the presence of solid impurities, which are not fully accounted for in the simplified model.

Nevertheless, the validation should be interpreted with the following limitation: experimental confirmation was performed under one operating condition only, namely a screw rotational speed of 80 rpm, safflower seed moisture content of 7-9%, and 2000 h of service. Therefore, the agreement between calculated and experimental data confirms the applicability of the model for preliminary engineering estimation under these conditions, but it does not yet cover all possible regimes of oilseed pressing. Future studies should include several rotational speeds, different moisture levels, feed rates, types of oilseed raw material, longer operating intervals, and direct pressure or friction measurements along the screw.

The most important detail is the agreement in the relative wear pattern: the calculated ratio for zones I:II:III was 1.00:1.46:1.92, while the experimental ratio was 1.00:1.46:1.96. Therefore, the final compression zone wears approximately twice as intensively as the initial compaction zone. This is associated with increasing pressure, greater density of the press cake mass, and more pronounced contact friction in the outlet part of the pressing chamber.

The analysis of international studies further proves the heterogeneity of wear in screw working elements. The researchers El-Ashry and Tawfik [44] evaluated the wear of a conical oil press screw separately in the feeding, crushing, and pressing zones; the authors showed that the most heavily loaded section depends on screw geometry and the location of maximum mechanical action on the raw material. In the work by Ariani et al. [12], the maximum wear rate of an industrial screw was associated with the final section in contact with the pressure cone. This agrees with the present calculation-

experimental results, where zone III and the section near the outlet die have the highest risk of surface damage.

Local studies on sunflower and safflower processing [1, 10, 11] show that changes in screw rotational speed, degree of raw material grinding, screw flight geometry, and pressure distribution affect oil yield, cake density, temperature, and energy consumption. These factors also determine the conditions of friction and contact loading; hence, their consideration is necessary not only to increase oil recovery but also to predict the service life of the screw.

Moisture content and rotational speed can significantly affect the predicted wear behaviour. An increase in moisture content may reduce dry friction and abrasive contact because of a more pronounced oil film, whereas excessive moisture can deteriorate cake formation, increase residence time, and raise discharge resistance. Conversely, reduced moisture content or increased mineral contamination may intensify abrasive wear. Higher rotational speed increases relative sliding velocity and the number of friction cycles per unit time; therefore, according to Archard's equation, it is expected to increase annual wear, especially in zone III. For this reason, future model calibration should include moisture content and rotational speed as variable input parameters rather than fixed operating constants.

The results obtained are consistent with data from the international literature on the mechanical pressing of oilseeds. In the work by Bogaert et al. [38], pressure, residual oil content, and material flow velocity were measured along the screw, thereby enabling identification of the functional zones of the press. The authors demonstrated that, in compression sections, high pressure leads to oil separation and the formation of dense press cake. In the present study, a similar effect is expressed analytically: zone III is characterized by the maximum pressure, the maximum wear criterion K_{wear}, and the highest annual wear.

Chapuis et al. [37] established that the pressing process is sensitive to raw material preparation and press settings, while minimum energy consumption may be observed at an oil extraction degree of 70-80%. This clearly explains the need to limit pressure: from a technological standpoint, it is not always reasonable to increase pressure to the maximum, since the additional oil yield decreases, whereas energy consumption and the load on the screw increase. In the present model, this conclusion is reflected through zone III of excessive compaction, where oil yield approaches saturation, but the wear criterion increases sharply.

The results are consistent with the study by Abdilova et al. [1], which shows that changes in screw rotational speed and degree of grinding affect not only oil yield but also cake density, temperature, and energy consumption. In this article, these factors are accounted for indirectly through the effective sliding velocity υ_{rel} and the pressure P(x). As a result, with an increase in rotational speed or a reduction in clearances, υ_{rel}, temperature, and local wear intensity are expected to increase, especially in the final compression zone.

The findings reported by Kovalyshyn and Tomyuk [39] also confirm that the energy consumption of pressing consists of material compaction, overcoming friction, and oil separation. In the present work, friction is incorporated into the engineering criterion $K_{wear} = \mu P^2$, thereby moving the analysis from a simple comparison of pressures to a more physically justified assessment of wear risk. At the same time, the model shows that even with the same coefficient of friction, increasing pressure from 9.23 to 17.69 MPa increases the integral risk by a factor of 3.67.

From a practical standpoint, the results are consistent with the conclusions of Indartono et al. [40], who found that increasing the feed rate and temperature improved oil yield. However, excessive feeding could clog the filtration module. Under oil press operating conditions, clogging or an increase in cake discharge resistance leads to a sharp rise in outlet-zone pressure, which, according to the proposed model, should accelerate wear on the final screw flights and press cage elements.

The practical significance of the obtained results lies in the targeted improvement of wear resistance in the most heavily loaded screw zones. Instead of strengthening the entire working surface, local surface strengthening or coating application should be concentrated on the final flights and the section near the

die, where the integral wear risk is highest. Such a zonal approach can reduce material consumption, lower restoration costs, and increase screw service life. Promising solutions include thermal spray coatings, coatings obtained by supersonic arc metallization, and surface strengthening technologies such as laser treatment or chemical-thermal treatment. The specific protection method should be selected with regard to operating conditions, coating adhesion, hardness, surface roughness, and the prevailing wear mechanism.

For a screw made of 40 Kh steel, it is reasonable to consider hardfacing, thermal spraying, or supersonic arc metallization of wear-resistant coatings onto the working side of the flights in zone III.

For service-life monitoring, it is recommended to perform periodic measurements of the screw flight profile, especially in zone III. Under single-shift operation, the basic calculation indicates a service life of approximately 5-6 years for the most heavily loaded section; under two-shift operation, this period may decrease to approximately 2.8-3.0 years, and under three-shift operation, to approximately 1.9-2.0 years. These values should be regarded as approximate estimates, since the actual service life depends on the moisture content and contamination of the raw material, coating hardness, stability of the clearance in the press cage, and the maintenance regime.

In the context of reliability management, this means that the inspection interval for the screw should be determined not only by calendar operating time but also by the actual load distribution across zones. For zone III, it is advisable to establish a shorter diagnostic interval, record changes in the screw flight profile on the technical condition map, and plan restoration or coating application before the maximum allowable wear depth is reached.

An additional 3D visualization of the calculation matrix expands the interpretation of the obtained results. Unlike zonal comparisons, response surfaces enable assessment of the sensitivity of wear to changes in operating factors. The most pronounced increase is observed when pressure and sliding velocity increase simultaneously, and when the coefficient of friction increases. This is consistent with the tribological nature of Archard's model and confirms that the final pressing zone is the most critical not only in terms of average pressure but also in the combined influence of contact and kinematic factors. The three-dimensional surface constructed from the experimental data also confirms the localization of maximum wear in the final compression zone.

CONCLUSIONS

The study's results confirm the non-uniform nature of wear on the working surface of the oil press screw. It was established that the wear intensity increases from the initial compaction zone to the final compression zone, which is associated with increased pressure, contact friction, and relative sliding of the material.

The calculation based on Archard’s model showed that the annual wear in zones I, II, and III was 0.166, 0.243, and 0.318 mm/year, respectively. Furthermore, the same pattern was confirmed using experimental assessment: the actual annual wear was 0.178, 0.260, and 0.348 mm/year. The deviation between the calculated and experimental data was within 7.2-9.4%, which indicates satisfactory agreement between the results and confirms the applicability of the proposed calculation approach for preliminary assessment of screw wear.

Zone III is the most heavily loaded and critical for loss of geometric accuracy, as it corresponds to the final compression and material discharge section. According to the integral wear criterion, the risk of wear in this zone is 3.67 times higher than in the initial compaction zone.

The practical significance of the results obtained lies in the justification for local rather than full-surface strengthening of the screw. The priority areas for monitoring, restoration, and application of a wear-resistant coating are the final flights and the zone near the die.

The suggested experimental-computational investigation may be used during the design, modernization, and technical maintenance of screw oil presses to predict component service life and select the most effective zones for protective strengthening.

From the perspective of production equipment management, the practical contribution of this work is that the proposed methodology enables the development of a risk-oriented maintenance plan by highlighting critical screw zones, predicting their service life, planning restoration, and reducing the likelihood of unscheduled oil press shutdowns.

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