International Journal of Technology 15(4) 1088-1101 (2024)
Received May 2023 / Revised December 2023 / Accepted March 2024

International Journal of Technology

http://ijtech.eng.ui.ac.id

Thermal Welding in the Neck of Vacuum Flexible Container with Self-propelled Welding Module

Kanat Khazimov[1,4], Zhadyra Sagyndykova[1,2], Zhanat Khazimov[1], Indira Daurenova[2], Yertugan Umbetkulov[2], Marat Khazimov[1,2,3*]

[1]Machinery Use Department named after Ivan V. Sakharov, Kazakh National Agrarian Research University, Abai Avenue 8, 050010, Almaty, Republic of Kazakhstan
[2]Almaty University of Power Engineering and Telecommunications named after G. Daukeyev, Baytursynuli 126/1, 050013, Almaty, Republic of Kazakhstan
[3] Al-Farabi Kazakh National university, 71 al-Farabi Ave., 050040, Almaty, Republic of Kazakhstan
[4]Suleyman Demirel University, Abylai khan street, 1/1, 040900, Kaskelen, Karasay region, Republic of Kazakhstan

Abstract. This study aimed to investigate the stability of weld seams in the neck of flexible containers made from polyethylene film for silage and storage of fresh ground corn mass as feed during thermal welding using a movable welding module. An analysis of the thermal conductivity of polyethylene film was conducted to determine temperature change pattern in the thin layer over time. The values obtained were used to establish optimal operating limits for the heating device during welding process. Subsequently, the resistance to rupture of the polyethylene film seams welded at different temperatures was evaluated by generating vacuum pressure in a specially designed installation. The results of polyethylene film PE-115 samples showed a pattern of limiting vacuum pressure values corresponding to different welding temperatures. The mathematical function obtained was used to identify the maximum value of the burst pressure of weld seams, which corresponded to 61.8 kPa at a temperature of 177°C. These results allowed for the determination of the optimal welding mode for sealing the container neck.

Keywords: Ensiling; Flexible container; Polyethylene welded seams; Welding module

1. Introduction

Climate change is projected to reduce potential yields in most tropical and subtropical regions. This is because the average global temperature by a few degrees can cause a decrease in yields at mid-latitudes, failing to compensate for changes in high latitudes, significantly in drylands (Lopatin, Muravychov, and Gritsevich, 2021). According to the United Nations, 75% of Republic of Kazakhstan territory is occupied by dry steppes and deserts. This phenomenon is attributed to changes in climatic conditions due to drought, leading to low yields of fodder crops, shortages, and high prices, contributing to food and nutrition deficiency for the population (ERA, 2021).

Kazakhstan, a traditional cattle-breeding country with a long history of animal husbandry, has faced difficult circumstances due to fodder scarcity. This situation is

---

[*] Corresponding author's email: mkhazimov@gmail.com, Tel.: +7 701 313 55 14

doi: 10.14716/ijtech.v15i4.6486

particularly challenging for a population that consumes the most livestock products. For example, an analysis of milk production data from the Committee of Statistics of the Republic of Kazakhstan showed that 78% of milk was produced by small-scale farms, while the remaining 22% was generated by large farms (Qazaq-Zerno, 2018). The average milk yield per cow is 2.341 kg/year, although this value varies significantly depending on the form of farms. For instant, large enterprises produce 4.338 kg/year peasant farms generate 1.849 kg/year, and subsidiary at 2.409 kg/year. However, farms in European countries such as Finland, Germany, Denmark, Sweden, and the Netherlands achieve approximately 10 thousand kg of milk per cow annually (EEC, 2018). In the U.S. and Canada, annual milk reaches 9.5 thousand kg per cow (AAFC, 2023). The main factors contributing to the success of family dairy farms abroad include a good full-fledged feeding base, technical equipment, and the availability of elite cattle.

In the animal breeding environment, feed costs account for 55% of total costs and approximately 77% of production costs. Meanwhile, enterprises buy approximately 45% of the feed and produce 55% (Yessimzhanova and Kaliyaskarova, 2014). To obtain high yields from intensive dairy cattle and realize genetic potential, each cow needs to be fed high-quality feed throughout the year. This includes at least 10 cwt of hay, 60 cwt of silage, root 22 cwt, and concentrated feed 16 cwt. Moreover, silage is the most important green canned fodder in winter, compacted and stored in airtight conditions which is often provided year-round food for ruminants in some regions (Victoria-Agro, 2020; Bondarev *et al.,* 2016).

The sustainability of livestock production due to changes in climatic conditions requires the development of a sufficient reserve of animal feed. One way to build up an insurable stock of succulent feeds is by harvesting maize silage. This process is carried out by acidification (anaerobic preservation by fermentation) of green feed crops such as corn (Borreani *et al.,* 2007). Ensilage fodder is stored in a structure called silo storage, which is a semi-hermetic or airtight structure. Currently, ensilage fodder storage is carried out mainly in stationary storage facilities according to global practice, which limits transport to remote areas (Bueno *et al.,* 2020). Regardless of the system, the main functions of silo and storage are to exclude air during the silage and prevent air from entering the ensilage fodder during storage (Borreani *et al.,* 2018).

The availability of affordable modern polymer materials has allowed the development of innovative methods for the production and storage of ensilage fodder (Niyazbayev *et al.,* 2022; Khazimov *et al.,* 2021; 2011). These methods include packaging in various volumes, which can be transported at any distance and stored for approximately 3 years (Sagyndykova *et al.,* 2021a; Nekrashevich, Mamonov, and Khazimov, 2020). However, several specific operations during packing are associated with compacting green mass under vacuum in flexible container made of polyethylene (flat) film. To obtain the necessary ensilage fodder without air, the vacuum process is carried out at negative pressures of 60-65 kPa (Sagyndykova *et al.,* 2021a; Invention Patent, 2019). The resulting ensilage mass in flexible container may be 20% higher in density compared to trench storage conditions. The required stability of the thickness of polyethylene film during the vacuum process of the ensilage mass is sufficiently substantiated, considering the elongation factor (Sagyndykova *et al.,* 2019a). Moreover, it is recommended that flexible container be made from finished sleeves of polyethylene film with a thickness not less than 0.200 mm, 1 grade of PE-100, or PE-115, without seams in length (Sagyndykova *et al.,* 2019b). When silage of approximately 850 kg/m3 is sealed, the walls of flexible container is subjected to a tensile stress. Similarly, weld seams along the neck edge, which are flat and two-sided in shape, are subjected to tensile stress to break layers of the film. The reliability of polyethylene film connecting seams for flexible container, experiencing high tensile stress in the field, is not well understood. Therefore, further research is required considering sheet polymer welding technology.

Previous studies have examined welding of polyethylene film made of sheet materials with a thickness above 2 mm. These materials are widely used in industries such as geomembranes, geotextiles, etc., with established carrying loads and appropriate standards for tensile tests (Kryzhanovsky *et al.,* 2005). However, there is a need to study welds of polymeric film of 0.5 mm thickness, which are mainly used as packaging materials. Due to the absence of high tensile stress, strict requirements are not set for this polymer film (Gov. Standard, 2015). Deviation in welding modes such as temperature, melting time, and surface pressure for film strips can change the reliability of the weldable layer near the joint. Weld seams of flexible container are subjected to bursting voltage when sealed by vacuum. Therefore, improper heating or insufficient pressure during welding can cause weld joints to fail, with overheating leading to breaking near the welding strip.

The scientific novelty of this study lies in the development of a technological process for preparing and storing silage mass in flexible container under vacuum. Additionally, the study explains theoretical and experimental substantiation of parameters and modes of compaction of a soft container for vacuuming silage mass. The developed technological and technical solutions were confirmed by patents of the Republic of Kazakhstan (Kaz NAU, 2022; 2019a; 2019b; 2019c; Utility Model, 2022; 2021; 2020; 2019a) and the Russian Federation (Utility Model, 2019b; 2018).

The importance of neck sealing technology for flexible container includes the limited volume of the compacted silage mass in vacuum-operated container. This allows the transportation of silage at any distance for a long time without damage. The technology also allows reliable sealing during movement, loading, and unloading operations, thereby preserving the vacuum condition to ensure quality silage feed. Scientific significance of this study lies in determining parameters for welding various thicknesses of polymer materials. This requires a comprehensive examination of the reliability of welding process for flexible container neck made from polyethylene film. Therefore, this study aimed to ensure the reliability of weld when sealing the neck of flexible container using a mobile welding module. To achieve the objective, several processes were carried out, including analytical substantiation of modes (temperature from time) for neck of flexible container made from polyethylene film with 0.2 mm thickness. Temperature welding modes of the module were also optimized based on experimental data of the reliability weld joint.

2. Materials and Methods

The proposed technology for the preparation and storage of ensilage fodder in flexible vacuum container made of polyethylene film in the field includes several processes. These include ensilage fodder preparation and storage in vacuum-operated container (Utility Model, 2018), which was carried out on a tractor-trailer in field conditions during corn mowing, as shown in Figure 1. The vacuuming of the silo consisted of loading the crushed corn mass into the flexible container with the addition of the oxidizer. This was followed by the densification of the loaded with ensilage fodder of the flexible container by welding the loading neck. Subsequently, corn mass is compacted in a pressurized flexible container by vacuum created through the return valve by vacuum pump. The compressed flexible container was lifted from the cartridge using a lifting device by hooking on the carrying Big-Bag (Sagyndykova *et al.,* 2021a; Nekrashevich, Mamonov, and Khazimov, 2020).

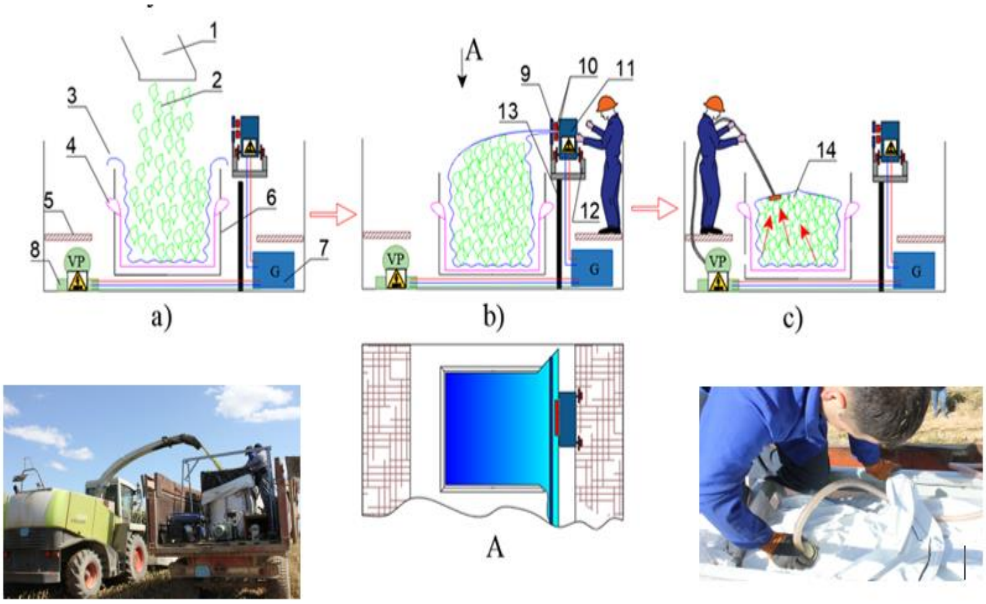


Figure 1 The silage fodder preparation process in flexible container, where a - loading of crushed green mass into container; b - welding of the container neck by welding machine; c – vacuuming; 1 - forage harvester; 2 – crushed green mass; 3 – flexible container; 4- Big-Bag; 5- operator workplace; 6- matrix for a flexible container; 7- generator; 8- vacuum pump; 9- clamp; 10- heating elements; 11- welding module; 12- sealer platform;13 - platform frame; 14- pressed container

When a freshly crushed corn mass is loaded into flexible container on a mobile tractor-trailer, sealing by welding the loading filler becomes a new and crucial process (Utility Model, 2019b). The process of welding the neck of flexible container consisting of a double layer of 2.5 m polyethylene film is carried out at an elongated state to avoid folds in the weld seams, as shown in Figure 2. Initially, one open side of the neck is cut from the finished roll of polyethylene film and used as a sleeve for pre-welding (Figure 2 a). This welded side is used as the bottom of a soft container (directed down) when lowered into a metal matrix form along with Big-Bag. Inside the Big-Bag and metal matrix, flexible container take the form of an open upper cap for loading the silo mass (Figure 2b). When loading of crushed fresh silage mass is achieved, soft container is sealed by welding the upper neck (Figure 2c). After vacuum pumping the air inside the flexible container with silo through the one-way valve, the soft container experience size reduction (Figure 2d). For welding the double layer of the filler into a single layer, a device is developed, facilitating the clamping of the extended film layers using profile rulers (the lower line is fixed, the upper detachable). This device enables the movement of welding module along the clamped strip of film through a guide rail, which is propelled by a drive roller integrated within the module.

Welding of protruding film layers from clamping rulers along the entire length is facilitated during movement by the welding module (Model DBF-900W, power 0,65 kW). This movement includes heating to melting point using opposite rotating tapes, followed by clamping of molten film layers under the necessary pressure (Figure 3).

The welding module moves along a horizontal rail located at flexible container neck by velocity ***v***. Furthermore, the axially arranged closed Teflon heating tapes with clamped layers are moved in a horizontal (opposite) direction to welding module. This leads to the formation of two layers of weldable neck film in a fixed state between the clamped heating tapes (Baskoro, Kurniawan, and Haikal, 2019). The linear velocities of the pressers' layer two Teflon belts and the welding module are equal in magnitude but opposite in direction. The research procedure includes analytical substantiation of modes (temperature and time) welding of flexible container neck from polyethylene film of 0.2 mm thick and optimization of temperature welding modes based on experimental data.

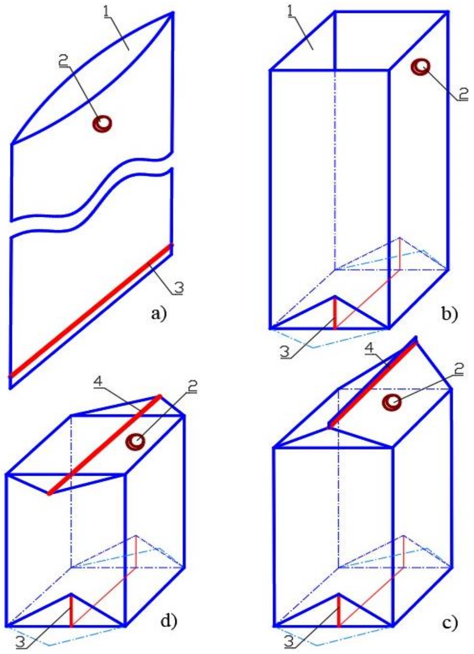


Figure 2 Flexible container manufacturing procedure, where 1-loading neck of the flexible container; 2- back valve: 3- welded joint of the down base of the container; 4- welded joint of the up base of the container

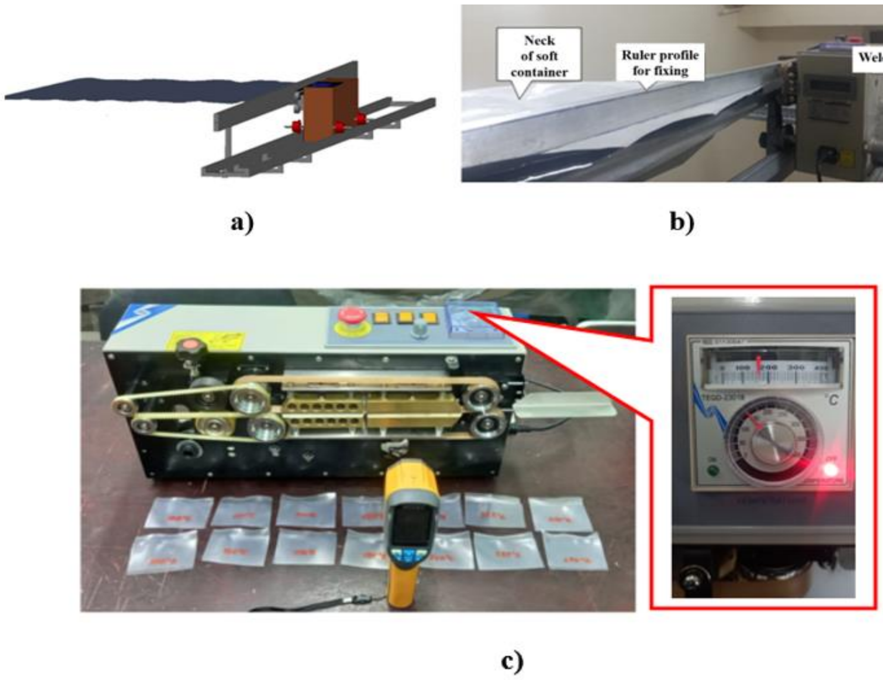


Figure 3 Welding of the neck of a flexible container with a self-propelled welding module, where a - diagram; b - general view of welding module; c - sealing machine « DBF-900W», thermal imager «Amtast AMF101» and sealed film samples «PE-115»

2.1. Method of analytical substantiation of welding modes (temperature and time) of flexible container neck from polyethylene film of 0.2 mm thick

The effective thermal power (***q***) in the case of low-voltage precision liner heaters, used for film welding, is expressed using formula 1 (Kataev, 2008):

$$q = 0.24\eta_э I^2 R, \tag{1}$$

where R - belt electrical resistance, *ohm*;

I - current flowing through the belt, *a*;

$\eta_э$ - The effective efficiency of the process, representing the ratio of the amount of heat introduced into the heated part to the thermal equivalent of the strip of electric power emitted by the belt.

Experimental data show that the efficiency index $\eta_э$ varies significantly based on the production conditions and design of the heating unit. A significant amount of heat is absorbed by the support box, the covered surfaces of the traverse presses, substrates, etc. Practically, when welding the film on the presses, the value of $\eta_э$ varies within 0.3÷0.6.

The spread of heat in products during welding occurs according to the law of thermal conductivity. The calculation of the temperature fields for the different methods of welding is based on the schematic determination of the tape processes. The process of heat propagation in an unlimited thermal-transfer body, according to the Fourier Thermal Conductivity Law, is expressed by the differential equation 2 (Popov and Popov, 2020).

$$\boldsymbol{\frac{\partial T}{\partial t} = a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)}, \tag{2}$$

where $a = \frac{\lambda}{\rho\, c}$ – *thermal diffusivity;*

c - heat capacity;

ρ - density;

λ - heat conductivity coefficient;

T - temperature value;

t – running time;

x, y, z - coordinates of the considered point.

The majority of problems related to the calculation of thermal processes in plastic welding different methods can be reduced to the schema of a linear thermal field by formula 3.

$$\boldsymbol{\frac{\partial T}{\partial t} = a\frac{\partial^2 T}{\partial x^2}}. \tag{3}$$

Dynamics of heating and cooling process of the thermal field formed by the movement of the source or coolant along the product during welding (ultrasonic, thermocone welding with a heated wedge, welding by jet of heated gas with or without an addition agent, etc.) can be calculated analytically using instantaneous point source method. The entire heating process is divided into discretely acting independent heat sources, and their effect is summed up (Burlutsky *et al.*, 2023). To simplify the problem, tasks are considered with constant boundary conditions and reduced to a one-dimensional type of heat propagation. In this case, the heating occurs symmetrically on both sides and is considered a one-way process. When the origin of the coordinates is located at the center of the joint, the edge conditions for unilateral heating can be represented by formula 4:

$$T(x, 0) = T_0; \tag{4 a}$$

$$\frac{\partial T}{\partial x}\Big|_{x=0} = 0; \tag{4 b}$$

$$T\left(\frac{h_0}{2}, t\right) = q(t). \tag{4 c}$$

where T_0- environmental temperature;

h_0- thickness of welded one layer of film (distance between heating surfaces equal to double film layer);

$q(t)$- heater temperature change law from time to time t.

In the presented analytic function (4c), the input parameter is the time (t) in seconds, which plays a key role in underheating or overheating a fixed film thickness (h). The thickness of the film is a fixed value of the film produced according to the standard.

The pressure at welding on the seam depends on viscosity of melt and the geometry parameters of polyethylene compound, including the width of the weld and film's total thickness. According to previous results (Kataev, 2008), the preliminary pressure is 0.09 MPa, and the temperature is within 160-170°C, with heating time of 3 seconds. Consequently, the translational tape speed (Rahman, Shoukaku, and Iwai, 2021) was selected from the condition by formula 5:

$$v = \frac{L}{t}, \tag{5}$$

where L – the length of the belt heating section (corresponds to the contact length of Teflon heating belts of Welding module);

t – belt heating time.

Welding parameters are further optimized experimentally, and corrections are related to the real property of polyethylene film. The theoretical studies allowed the selection of indicative limits of welding parameters for the experiment.

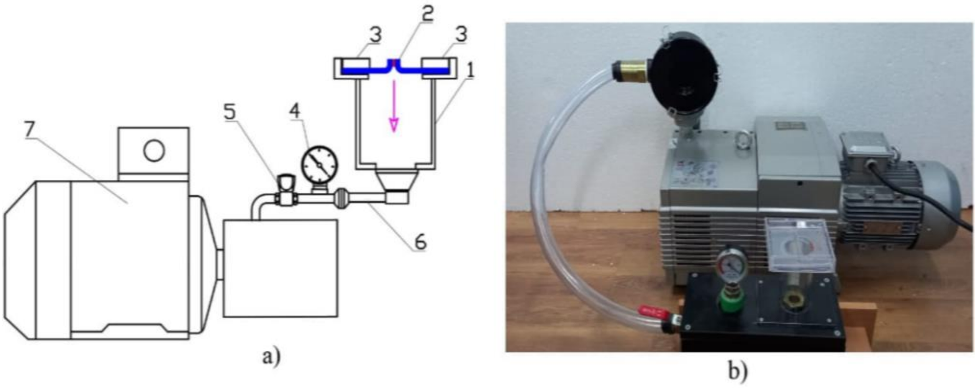
2.2. Method of experimental strength of polyethylene film seams for flexible container

Samples of 200 μm film with welded joints were tested to determine the strength of polyethylene film used in vacuuming silage mass (Sagyndykova *et al.,* 2021a; Utility Model, 2019b). The connection of the two film layers, each with a 200 μm thickness was made by thermal welding using the equipment presented in Figure 2. During the welding operation, the temperature variations used were 100°C, 125°C, 150°C, 200°C, and 225°C.

The welding pressure on this equipment was selected by adjusting the space between the upper and lower heating Teflon belts (Rahman, Shoukaku, and Iwai, 2021). The adjustment was ensured by changing the position of the tensioning roller of the Teflon heating tapes before the appearance of the surfacing at the seam mouth on the welded surface. The pressure on the welded film was determined after measuring the Teflon tape roller force, which corresponded to 2.3 kg/cm^2. At this pressure, there was no overlap at the mouth of the suture, eliminating thinning of the welded layers in seam area. Welding speed was calculated using the formula (5) and was set to 0.066 m/s for the grade of polyethylene PE-115 (Kulik and Nilov, 2020; Utility Model, 2019a).

For the test, samples of 100x200 mm in size with welded joints were cut from the welded strip of the film. These samples were subjected to testing on a specially designed device, as shown in Figures 4 a and b. Furthermore, seamed film samples were tested at vacuum pressure from 40 kPa to 65 kPa. During the testing, vacuum was created by vacuum pump (Model ERSTVAK VP80, capacities 80m^3/h, power 2.2 kW). The graduated open-top glass cylinder 1 designed device, a sample of polyethylene film 2 with a welded seam, was secured tightly using a steel clamp 3 with a rubber gasket, forming a sealed connection to the glass cylinder (Madani *et al.,* 2023).

Negative pressure was applied using a vacuum pump to test the strength of the weld joints in polyethylene film fixed to the end of the cylindrical receptacle. The test film with the weld joint was sucked into the glass vessel under the influence of vacuum, forming a paraboloid shape. The maximum vacuum value was fixed at the position of the vacuum meter needle. When the joint burst in the center of the stretched film, the needle returned to zero. This test was repeated five times for each sample at the same film welding temperature, as shown in Figure 5. The weld obtained before testing are presented in the second column of the table. The temperature conditions of the heating device of the mobile welding module were checked by thermal imaging «Amtast AMF101», with wave temperature ranging from 20°C to 300°C. In the third column, the breaking points of the welded seam are surrounded by the red circle, and the test repeat data is presented in column 4.



a) b)

Figure 4 Diagram (a) and general view (b) of device for testing of welded plastic film, where 1 - graduated open-top glass cylinder; 2 - sample of polyethylene film; 3 - clamp; 4 - vacuum gauge; 5 - a shut-off valve; 6 - the vacuum line; 7 - vacuum pump

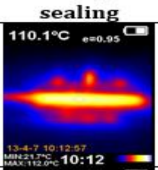
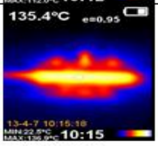
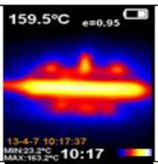
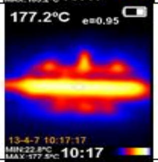
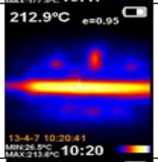
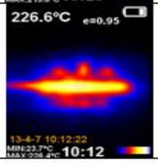
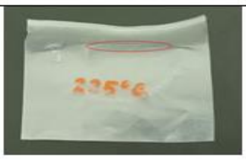
Before testing	Thermal imagery reading of sealing	After testing	Destructive vacuum pressure
			$P_{vac\,1}$ = 44 kPa P_{vac2} = 46 kPa P_{vac3} = 45 kPa P_{vac4} = 47 kPa P_{vac5} =43 kPa **P_{vacavg} = 45 kPa**
			P_{vac1} = 54 kPa P_{vac2} = 57 kPa P_{vac3} = 54 kPa P_{vac4} = 58 kPa P_{vac5} = 52 kPa **P_{vacavg} = 55 kPa**
			P_{vac1} = 58 kPa P_{vac2} = 60 kPa P_{vac3} = 59 kPa P_{vac4} = 58 kPa P_{vac5} = 61 kPa **P_{vacavg} = 59 kPa**
			P_{vac1} = 60 kPa P_{vac2} = 62 kPa P_{vac3} = 61 kPa P_{vac4} = 64 kPa P_{vac5} = 63 kPa **P_{vacavg} = 62 kPa**
			P_{vac1} = 60 kPa P_{vac2} = 60 kPa P_{vac3} = 60 kPa P_{vac4} = 62 kPa P_{vac5} = 58 kPa **P_{vacavg} = 60 kPa**
			P_{vac1} = 56 kPa P_{vac2} = 59 kPa P_{vac3} = 56 kPa P_{vac4} = 58 kPa P_{vac5} = 55 kPa **P_{vacavg} = 57 kPa**

Figure 5 Samples of polyethylene film with weld seams at different temperatures

The test data obtained were statistically processed to assess error and reliability using standard methods (Gritsyuk, Mirzoeva, and Lysenko, 2007).

3. Results

The calculation results for one-dimensional heat distribution according to equations (3) and (4) is presented as follows by formula 6 (Popov and Popov, 2020; Bukhmirov, 2014; Budak, Samarsky, and Tikhonov, 2004; Korolev, 2022):

$$T(x,t) = \frac{qe^{-\frac{x^2}{4at}}}{4\pi at} \tag{6}$$

where, $T(x,t)$ - the temperature at the point x in the film layer between the heater and the seam center at the time $\boldsymbol{t}$ after heating.

The graphical interpretation of function (6) facilitated the determination of heating time of the polyethylene film layer at the initial temperature values at a remote point from the heater (Figure 6). Since an excessive heating time increase could cause the film to melt, reducing the heating time would lead to poor melting.

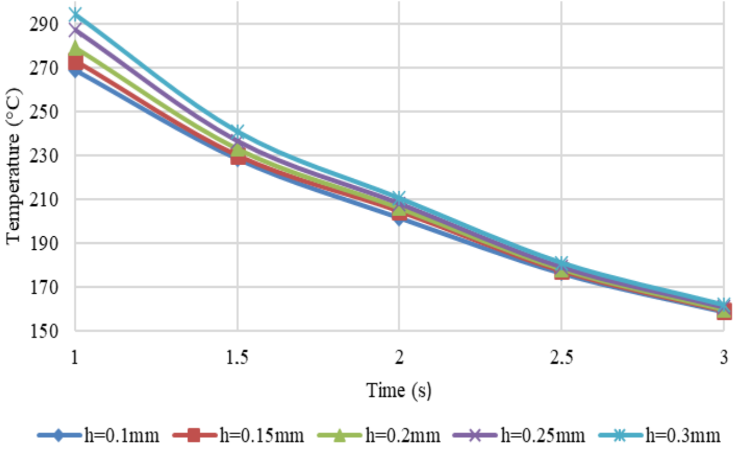


Figure 6 Temperature change of film layer from heating time in polymer film thickness

Based on the results, the graphical dependence of polyethylene film resistance on peeling and tearing due to tensile pressure induced by vacuum was constructed, as shown in Figure 7.

4. Discussion

The analysis of the temperature field distribution in the welded polyethylene film layer of approximately 0.3 mm was performed using analytical substantiation. Since the heating element is completely in contact with the welded surface, the heat flow was assumed to move in the direction of the film thickness. Consequently, a one-dimensional time temperature distribution was assumed for different film thicknesses (h = 0.1 mm, h = 0.15 mm, h = 0.2 mm, h = 0.25 mm, h = 0.3 mm). In this analysis, the thickness of the film was considered boundary conditions, while time served as the initial and final conditions. According to the obtained equation (6), a graphical interpretation of the results was constructed, which allowed the selection of the time parameter when heating the necessary thickness of the layer. The welding module speed was determined considering the length of the heating source, which was the Teflon film tape length of touch.

To determine the optimal temperature range, the first temperature $\boldsymbol{T}$ derivative of the second-order $\boldsymbol{P}$ function (from formula 7) was obtained and equaled to zero by formula 8.

$$P = -0.0027T^2 + 0.9561T - 23.426 \tag{7}$$

$$\frac{dP}{dT} = -2 \cdot 0.0027T + 0.9561 \tag{8}$$

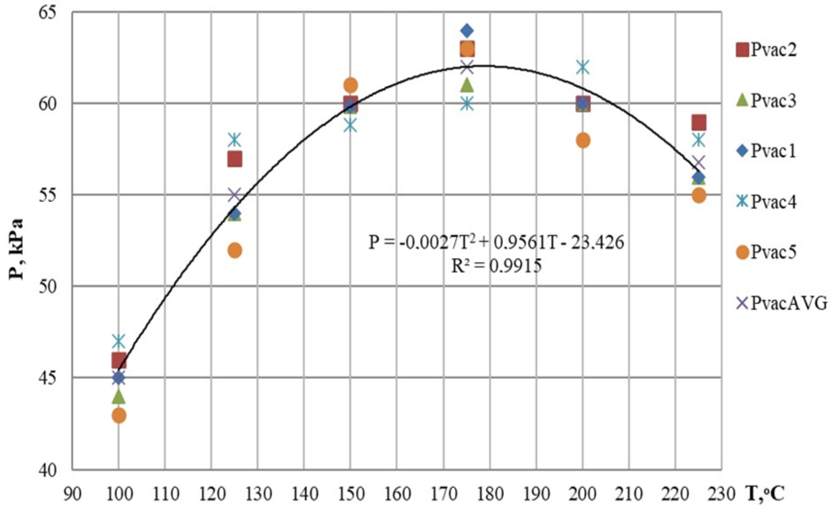


Figure 7 Dependence of film weld seam braking (bursting) pressure on the temperature of welding

$$-2 \cdot 0.0027T + 0{,}9561 = 0,$$
$$0.0054T = 0{,}9561,$$
$$T = 177^{0}\text{C}.$$

Substituting the temperature value $T = 177^{0}\text{C}$ formula (7), we get:

$$P = -0.0027 \cdot (177)^2 + 0.9561 \cdot 177 - 23.426 = -84 + 169.2297 - 23.426 = 61.8 \text{ кPa}.$$

As a result of solving the equation obtained from the first-order derivative, the roots found showed the optimum temperature T, which corresponds to the maximum pressure $\boldsymbol{P}$. This pressure corresponds to the apex of the parabola represented in Figure 7.

According to the graphical model, weld resistance (breaking) of 200 μm thick polyethylene film when vacuum silage in flexible container can be recommended for welding modes 170°C – 200°C, with vacuum pressure of 60 kPa.

Figure 4 shows the stratification and seam fracture rates based on the data graph in Figure 7. The left side of the curve from the maximum point is related to the insufficient melting of polyethylene film. The damage is evident in the pictures of the film samples, where higher temperature, correlates with decreased damaged size. Therefore, as the welding temperature of the film seam increases, burst pressure value is reduced. This phenomenon occurs due to the closeness of the molten polymer layer to the viscous current state area (T_{tfc}) of the alloy, allowing a good transition of two molten welded layers of film. After the transition of the graph's maximum point, burst pressure value is reduced. This shows that as the welding temperature increases, the molten film layer moves from a viscous current state (T_{tfc}) into the destruction state of the thermoplastic (T_d), with a significant decrease in joint strength, and the weld seam edge becomes thin.

The provision of reliable tightness of the soft container by thermal welding of the loading neck after filling with green mass allows compacting with vacuum pressure of 61.8 kPa. The compacted green mass in the soft container is mainly 20% higher in nutritional value compared to blank in the classical method in trench conditions (Sagyndykova *et al.,* 2021a). Moreover, energy consumption at the stage of sealing and transportation is reduced by an order of magnitude (Sagyndykova *et al.,* 2021b). Distinctive operations such as welding, compacting, and transportation are presented according to the proposed and classic methods in Table 1 for comparative estimation of energy consumption.

Table 1 Comparative energy intensity of different operations at silage preparation per 1.000 cattle in different methods

Silage preparation methods	The mass of silage feed, ton	Sealing, kW ×hour	Densification, kW ×hour	Transportation, kW ×hour	Unloading, kW ×hour	Total, kW ×hour
Densification with heavy tractors in trench	72500.0	-	487980.0	167280.0	90624.0	745 884.0
	1.0	-	6.73	2.3	1.25	10.38
By vacuum densification on mobile unit	72500.0	1570.4	43500.0	54360.0	181200.0	280 630.0
	1.0	0.022	0.6	0.75	2.5	4.07

Based on the results, the total energy consumption of the proposed technology is 2.5 times less than the old classical technology. This is because, at the compacted stage, the process is continuous to avoid relaxation which occurs in the classical method. During transportation, the filling ratio of the transported cargo is increased by the compacted mass. These advantages are achieved when the flexible thermoplastic container is securely sealed.

5. Conclusions

In conclusion, this study was carried out to determine the optimum parameters and welding modes for the loading neck of flexible polyethylene container designed for vacuum sealing of silage mass. Based on theoretical studies, a time-dependent temperature change in the form of a one-dimensional field for polyethylene film thicknesses from 0.1 mm to 0.3 mm was obtained. For the standard thickness of 0.2 mm of polyethylene film sleeve, the resulting dependence allowed the calculation of kinematic parameters such as speed and movement time of the welding module, including temperature regime of the mobile welding module. The tests performed for six welding modes, with five repetitions each, for a 0.2 mm polyethylene film enabled the determination of optimum weld breaking limits. These included weld temperature of 177°C when polyethylene was melted at 225°C, which resisted burst pressure of 61.8 kPa. Vacuum sealing of the silo in flexible container was permissible at this vacuum pressure at a film thickness of 200 μm. This temperature was identified as the minimum for welding open parts of a 200 μm thick flat polyethylene flexible silo container. To perform similar welding of different thicknesses, a further study should be conducted to determine the temperature range for the welding machine. Additionally, investigations should be carried out on the design of specialized mobile welding devices for polyethylene film of 0.5 mm thick.

Acknowledgments

This study was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Years for research grant are 2022 -2024. Grant No. AP13067761).

References

AAFC (Agriculture and Agri-Food Canada), 2023. Average Production Per Cow and Breed for Selected Countries. Available online at: https://agriculture.canada.ca/en/sector/animal-industry/canadian-dairyinformation-centre/statistics-market-information/dairy-animal-genetics/production-breed/per-cow, Accessed on June 16, 2024

Baskoro, A.S., Kurniawan, R.P., Haikal., 2019. Evaluation of the 2-Axis Movement of a 5-Axis Gantry Robot for Welding Applications*. International Journal of Technology*, Volume 10(5), pp. 1024–1032

Bondarev, V.A., Kosolapov, V.M., Klimenko, V.P., Krichevsky, A.N., 2016. *Preparation of Silage and Haylage Using Domestic Biological Preparations.* FGBNU All-Russian Research Institute of Feeds named after. V.R. Williams

Borreani, G., Tabacco, E., Cavallarin, L. (2007). A New Oxygen Barrier Film Reduces Aerobic Deterioration in Farm-Scale Corn Silage. *Journal of Dairy Science.* 90(10), pp. 4701-4706. https://doi.org/10.3168/jds.2007-0310

Borreani, G., Tabacco, E., Schmidt, R.J., Holmes, B.J., Muck, R.E., 2018. Silage Review: Factors Affecting Dry Matter and Quality Losses in Silages. *Journal of Dairy Science*, Volume 101(5), pp. 3952–3979

Budak, B.M., Samarsky, A.A., Tikhonov, A.N., 2004*. Collection of Problems on Mathematical Physics*, 4th Edition. Physizmatlith

Bueno, A.V., Lazzari, G., Jobim, C.C, Daniel J.L., 2020. Ensiling Total Mixed Ration for Ruminants: A Review. *Agronomy*. Volume 10(6), pp. 2–18

Bukhmirov, V.V., 2014. *Heat and Mass Transfer: Textbook.* Manual. Ivanovo: Federal State Budgetary Educational Institution of Higher Professional Education. Ivanovo State Energy University named after V.I. Lenin

Burlutsky, E., Balzamov, D., Bronskaya, V., Kharitonova, O., Khairullina, L., Solovyeva, O., 2023. Influence of Temperature on the Thermal Properties of the Core Material - the Coefficient of Temperature Conductivity, Specific Heat Capacity, and Thermal Conductivity. *International Journal of Technology*, Volume 14(2), pp. 443–454

EEC (Eurasian Economic Commission), 2018. Review market of milk and dairy products Member States of the Eurasian Economic Union for 2013 – 2017. Agricultural Policy Department. Available online at: https://eec.eaeunion.org/upload/medialibrary/b5a/OBZOR-po-moloku_za-2013_2017-g.pdf, Accessed on November 15, 2022

ERA (Economic Research Institute), 2021. Drought in Kazakhstan - A Consequence of Global Climate Change. Available online at: https://economy.kz/ru/Novosti_instituta/id=3087#, Accessed on December 28, 2022

Gov. Standard, 2015. Gov. Standard 56155-2014. Welding thermoplastics. Extrusion Welding of Pipes, Pipeline Parts and Sheets. Official edition. Standardinform

Gritsyuk, S.N., Mirzoeva, E.V., Lysenko, V.V., 2007. Mathematical Methods and Models in Economics. UK: Cambridge University Press

Invention Patent, 2019. Invention Patent No.33744. Set of Machines and Equipment for The Silo of Green Material in Flexible, Vacuum-Operated, Airtight Film Containers/Kaznaru

Kataev, R.F., 2008. *Welding of Plastics*. Ekaterinburg: USTU-UPI.

Kaz NAU, 2019a. Patent. 33415. Set For Loading, Transport, Vacuum, Silaging and Storage of Silage Feeds (2017/0540.1). Republic of Kazakhstan

Kaz NAU, 2019b. Patent. 33425. Valve For Container Used for Silage of Feeds (2017/0767.1). Republic of Kazakhstan

Kaz NAU, 2019c. Patent. 33744. Set of Machinery and Equipment For Silage of Green Plants in Soft Vacuum Containers Made of Airtight Film (2018/0204.1). Republic of Kazakhstan

Kaz NAU, 2022. Patent. 35668. Method of Preparation and Storage of Silage Feed (2021/0015.1). Republic of Kazakhstan

Khazimov, J.M., Khazimov, M.Z., 2011. To Justification of The Parameters of The Work Wheel of The Seedling Planting Device for Soil Mulching. *Journal of the University of Chemical Technology and Metallurgy*, Volume 46(1), pp. 99–104

Khazimov, K.M., Niyazbayev A.K., Shekerbekova Z.S., Urymbayeva A.A., Mukanova G.A., Bazarbayeva T.A., Nekrashevich V.F., Khazimov M.Zh., 2021., A Novel Method and Device for Plastic Mulch Retriever. *Journal of Water and Land Development*, Volume 49 (IV–VI), pp. 85–94

Korolev, V.N., 2022. *Heat and Mass Transfer: Educational Manual.* Ekaterinburg: Ural Publishing House

Kryzhanovsky, V.K., Burlov, V.V., Panigatenko, A.D., Kryzhanovskaya, Yu.V., 2005. *Technical Properties of Polymeric Materials: Study on The Right Manual*. 2nd Edition. Profession

Kulik, V.I., Nilov, A.S., 2020. *Technology of Composites Based on Thermoplastic Binders: Manual.* State Technology

Lopatin, V.N., Muravychov, A.I., Gritsevich, I.G., 2005. *Global Climate Change, Problems, and Prospects of Implementation of the Kyoto Protocol in the Russian Federation: Training Package on The Program of The Course "State Environmental Management".* WWF-Rusia

Madani, N.A., Purnamaningsih, R.W., Poespawati, N.R., Hamidah, M., Rahardjo, S., Wibowo, D.K., 2023. Detection of Low Hydrostatic Pressure Using Fiber Bragg Grating Sensor. *International Journal of Technology.* Volume 14(7), pp. 1527–1536

Nekrashevich, V., Mamonov, R., Khazimov, M., 2020. Theory and Practice of Feed Silage in Containers Made of Airtight Film. *In:* BIO Web Conference. International Scientific-Practical Conference “Agriculture and Food Security, Volume 17. Available online at: https://doi.org/ 10.1051/ bioconf/20201700041, Accessed on February 28, 2023

Niyazbayev, A., Pegna, F.G., Khazimov, K., Sagyndykova, Z., Khazimov, M., 2022. Power Need of an Implement for Removing Polymer Residues from The Soil Surface in Kazakh Horticulture. *Journal of Agricultural Engineering*, Volume 53(3), p. 1382

Popov, A.I., Popov, I.Yu., 2020. *Basic Equations of Mathematical Physics*. Tutorial. St. Petersburg: ITMO University

Qazaq-Zerno, 2018. Average Milk Yield in Kazakhstan. Available online at: https://kazakh-zerno.net/137679-srednij-nadoj-moloka-v-kazakhstane-v-proshlom-godu-sostavil-2341-kg/, Accessed on February 12, 2023

Rahman, J., Shoukaku, Y., Iwai, T., 2021. An Experimental Study of the Effect of Load and Moving Speed on Free Rotating Rubber Contact using Fluorescence Microscopy. *International Journal of Technology,* Volume 12(4), pp. 781–790

Sagyndykova, Zh., Nekrashevich, V., Khazimov, K., Kassymbayev, B., Khazimov, M., 2021a. Research and Development of Essentials for Silage Preparation, Transport and Storage in Flexible Containers of Optimal Volume. *Acta Technologica Agriculturae*, Volume 24(2), pp. 72–78

Sagyndykova, Zh.B., Berdimurat, A.D., Khazimov, K.M., Niyazbaev, A.K., Khazimov, M.Zh., 2021b. Determination of the Efficiency of The Technology of Preparation and Storage of Silage in Soft Vacuum Containers. *Journal Bulletin of Science of the Kazakh Agrotechnical University named after S. Seifullin,* Volume 4(111), pp. 50–57

Sagyndykova, Zh.B., Necrashevich, V.F., Khazimov, K.M., Khazimov, M.Z., 2019b. Food. Ecology. Quality. *In*: Conference Materials XVI Mezhunar. Scientific And Practical Conference. Barnaul, Volume 2, pp. 158–161

Sagyndykova, Zh.B., Necrashevich, V.F., Torzhenova, T.V., Khazimov, K.M., Khasimov, M.Z., 2019a. Theory and Practice of Silage of Feed in Containers of Airtight Film. *Research, Results,* Volume 3, pp. 375–382

Utility Model, 2018. Utility Model No. 183627. Airtight Film Container for Silage Feed/Russia

Utility Model, 2019a. Utility Model No. 4520. Container For the Preparation and Storage of Silage Feed/Republic of Kazakhstan

Utility Model, 2019b. Utility Model No. 193970. Container For the Preparation and Storage of Silage Feed / Russia

Utility Model, 2020. Utility Model No. 5469. Air-Tight Film Container Cassette for Feed Silage (2020/0470.2)/Republic of Kazakhstan

Utility Model, 2021. Utility Model No. 6308. Silage Harvesting Hose of Forage Harvester (2021/0032.2) Republic of Kazakhstan

Utility Model, 2022. Utility Model No. 7437. Vehicle (Container Vessel) For Receiving the Ground Mass from The Harvester) and The Russian Federation (2022/0407.2)/Republic of Kazakhstan

Victoria-Agro, 2020. Status and Prospects for Improving Dairy Cattle Farming. Available Online at: http://www.viktoriy.ru/sostoyanie-perspektivi, Accessed on February 12, 2023

Yessimzhanova, S.R., Kaliyaskarova, E.A., 2014. Analysis of Meat Market and Meat Products Market in Kazakhstan. *Procedia - Social and Behavioral Sciences,* Volume 109, pp. 1216 – 1219