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HYDRO-MECHANICAL PROCESSING OF RAW BEEF BY MASSAGING: THEORETICAL BASICS AND PRACTICAL APPROACHES

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Abstract. *Upgrading of the equipment for hydro-mechanical processing of raw meats is important both in terms of ensuring the proper profitability of production and in terms of providing consumers with valuable protein meat products of excellent taste. Salting of raw meats, which is related to hydro-mechanical processing, is a complex process embracing mass exchange, transformations of protein and other substances, changes in the water-holding capacity of meat, changes in its microstructure, etc. There are different approaches to the machine and apparatus design and technological modes of hydro-mechanical processing of raw meats. Meat massagers / tumblers used in industry are equipped with devices for cooling and vacuuming the working space. Active research is being conducted to determine the rational duration of work / standstill during processing of raw materials in a drum. For beef, it is recommended to use the mode of alternating 30 min of work with 30 min of standstill for 8-12 h or other modes. The purpose of the article is to present and logically substantiate the results of studies of massaging the processing of meat raw materials in the drum of the massager under different modes of technological processing. Massaging of raw meats was carried out using a laboratory unit for wet salting of meat raw materials (drum massager) Ya5-FMS of our own design. Rheological characteristics were determined using an electromechanical universal testing machine SANS CMT2503. The duration of salting of raw meats depends on their type and quality characteristics, morphological composition, pH, degree of autolysis, mass and shape of meat cuts, quantity, quality and temperature of brine, as well as on the efficiency of the equipment used. Even more effective penetration of curing ingredients is achieved by using a pulsating vacuum, in which the processed meat raw materials are exposed to alternating loads: atmospheric pressure – vacuum. An increase in the intensity of hydro-mechanical processing of raw meats causes corresponding changes in the structure of muscle fibers – their swelling, the occurrence or increase of transverse-slit integrity violations, disruption of membrane structures, loosening and swelling of myofibril proteins. All of the above indicates that the use of pulsating vacuum and drum cooling not only improves, but also significantly accelerates the process of wet salting of raw meats raw materials in the production of ham products. The use of vacuuming in general and pulsating vacuuming in particular contributes to the intensification of the process of wet salting of raw meats. Therefore, the use of massagers with cooling and a pulsating vacuum system is an optimal design solution in terms of product quality and acceptable production profitability for meat processing enterprises.*

Key words: raw meats, brine, salting, maceration, vacuuming.

Definition of the problem. Permanent tasks of the domestic food manufacturing industry of Ukraine consists in producing and provision of high quality foodstuffs to the population which is of uppermost importance for the socio-economic development of society [1], the same is completely true with the Ukrainian meat industry [2]. In the European cultural tradition, in the paradigm of which Ukraine and its people are developing, the consumption of meat products was and remains a sign of well-being and prosperity. And numerous minced meat products, and, especially, delicacies made from whole-muscle raw materials, not only served as a utilitarian source of protein and fat, but also represented the core of national cuisine. Accordingly, the entire meat industry, including its personnel and machine-technological base, have always responded more quickly to various innovations in technical progress, reflected in new technologies and advanced specialized production equipment. Of course, in this area there are still problems that require an effective solution [3].

The above also fully applies to equipment for the production of gourmet whole-muscle meat products. It should be noted that it is not easy to provide meat products with a high delicacy status, since it is difficult to obtain a product from tough muscle tissue that is acceptable in terms of sensorial properties and meets consumers' expectations – this is especially true for beef ham products [4]. A wide range of specialized technological equipment facilitates the effective implementation of this technological process – these are knife and wringer tenderizers, devices for preparing brines and for static salting of raw meat, various brine injectors, meat massagers/tumblers, as well as auxiliary equipment for the meat salting. Further upgrading of equipment for hydro-mechanical processing of raw meats is therefore important both in terms of ensuring the proper profitability of production and in terms of providing consumers with valuable protein meat products of excellent taste. Salting of raw meats, which is related to hydro-mechanical processing, is a complex process of various natures: mass exchange, transformation of proteins and other substances, changes in the water-holding capacity of meat, changes in its microstructure, etc. Understanding the theoretical basics of the salting process allows for the rational organization of the production of the above-mentioned meat products by using new technological methods and special equipment to improve the consistency

and texture of finished products, as well as to reduce the time of technological processing [5].

Analysis of recent achievements and publications. Salting of raw meats aims at protecting it from microbiological spoilage, as well as achieving the appropriate properties of finished products: subjective sensorial characteristics – taste, aroma, color and consistency as well as objective physical and chemical characteristics – texture, chemical composition, etc. [6]. The most common, cheap and well-studied salting agent is sodium chloride [5].

Long-term practice shows that combining salting of meats with mechanical effects on them promotes the intensification of biochemical processes in muscle tissue. The term "hydro-mechanical processing of raw meat" is used to define the said combined processing. As a rule, meat is first saturated with curing brine using portable manual or automatic multi-needle brine injectors, after which, together with the additional amount of brine, it is processed in meat massagers [7]. As a result, muscle tissues acquire elasticity, and the meat absorbs the curing brine in an amount of up to 10 – 12% of the original mass of the raw material. Due to mechanical processing, the integrity of the meat cell membranes is disrupted, and the penetration of the brine is facilitated as a result of the destruction of the connective tissue shell around the muscle fibers, which swell under the action of curing substances. At the same time, the yield of the finished product increases, which acquires a soft and delicate consistency [8]. The devices used to perform this technological operation, meat massagers, are cylindrical rotating drums in which pieces of meat rub against each other, as well as against the walls, rise up and fall inside the working container. These machines are also called meat tumblers (from the English word “to tumble” – to turn over, to somersault) [9,10].

Technologies that involve only injection of meat raw materials or only massaging are also used. For example, large-sized cuts are salted without subsequent massaging, using hand-held injectors with one or more needles. Among technologists, there are supporters of using only injection when salting all types of meat and bone raw materials, since, in their opinion, pieces of meat are excessively damaged by collisions and falls in the rotating drum of the massager. According to the same specialists, when implementing the sequence of injection + massaging operations, mechanical processing may not provide the expected increase in weight by 12%, since with excessively intensive massaging, proteins remain in the brine, since they are washed out of the raw materials, which is observed, for example, when massaging pork for more than 5.5 h [5,11]. At the same time, when using viscous multi-component brines that clog the injector needles, it is not recommended to inject meats and to use only the mechanical processing in the drum of the massager [5,12].

The modes of massaging raw meats, due to their diversity and the technological goals pursued, continue to remain the focus of attention of meat science specialists as the said process facilitates the distribution of the previously injected pickling solutions within meat cuts. The protein contained in muscle fibers tends to be extracted and solubilized thus promoting the water binding in meats and adhesion of pieces when a restructured product is treated thermally [13-17]. The longer is the massaging process the lower is exudate’s viscosity and, consequently, a meat product is more palatable [18], but there is also the evidence that a longer tumbling time results in the harder texture of a product [16]. Rational modes of massaging raw materials for the production of the South African national product from beef are substantiated in [19]. Experiments to determine the influence of massaging modes on the physical and chemical characteristics of meat products are described in [19] and the main three factors of the process are identified. According to [20], the first factor is the tumbling mode (for instance “strong tumbling” at 8 rpm in a 180 L tumbler filled to 50% and “soft tumbling” at 10 rpm in a lab tumbler of ∅ 0,1 m intended to treat a single meat cut); the second factor is the treatment time (15 min and 60 min); the third factor is partial vacuum (residual pressure $2 \cdot 10^{-4}$ N/m^2) – being or not being applied Miscellaneous messaging methods with the use of electrical stimulation are characterized in [21]: new processing technologies such as ultrasound, high-pressure processing, pulsed electric field, new tumbling technology and alkaline electrolyzed water can modify the structure of muscle proteins and improve the textural quality of meat products, reducing the amount of phosphates added in meat products without adding other clean label ingredients.

In the meat industry, massaging of meat raw materials in interval mode is widely used, when the rotation of the drum alternates with its standstills. During a standstill, meat pieces loosen up, these beginning to suck the pickling solution in when the drum is rotating. Such treatment modes are considered to be practical: meats with bones – from 24 to 36 h, 8 rpm, rotation from 10 to 20 min, pause – 50 min; meats without bones – from 24 to 36 h, 16 rpm, rotation from 20 to 30 min, pause – 1 h; smoked and boiled fillet in a casing – from 24 to 48 h, 16 rpm, rotation – from 15–20 min, pause from 45 to 60 min [22]. Beef is recommended to be treated for 16 h alternating rotation from 20 to 40 min and pause of the same duration, pork – 12 h, rotation 15 to 30 min, a pause – from 30 to 45 min [23]. Beef can also be treated for 12h (at 20 rpm) and 8 h (at 5 rpm) – a drum shall be 70% full, 30 min of operation with 30 min of pause shall be altered [24]. The following modes of pork processing are considered appropriate: fill factor 0.7; total number of strokes 2400, drum rotation speed 6 rpm [25].

Since the extraction of salt-soluble proteins occurs most intensively at a temperature of 2.2 °C to 3.3 °C, the internal space of the working drum of the massager with the brine and meat raw materials being massaged is cooled by directly introducing carbon dioxide or by feeding the cooled medium into the heat exchange jacket of the drum. Massaging very fatty raw materials requires the use of higher temperatures so that the fat and connective tissue become more plastic - then the whole-muscle meat products produced from such raw materials are softer. The internal space of the drum is vacuumed in order to limit the foaming of the exudate, while more effective penetration of curing substances into the cuts is achieved by vacuuming in a pulsating mode, when the processed meat raw materi-

als are exposed to alternating loads in the vacuum – atmospheric pressure cycle. Due to this processing mode, the water-holding capacity of the meat increases, and the meat products acquire the necessary soft and juicy consistency acceptable to consumers [23].

The purpose of the article – to present and logically substantiate the results of the studies of massaging the processing of raw meats in the drum of the massager within different modes of technological processing.

Materials and methods. Massaging of raw meats was carried out using a laboratory unit for wet salting of meat raw materials Ya5-FMS (Fig. 1), on the frame of which a working sealed drum of geometric capacity 0.1 m^3 with radially located hollow ribs, into which a coolant can be supplied, is installed in a bearing support. The loading / unloading door of the drum is equipped with a sealed lid with a device for vacuum intake and discharge. The unit is also equipped with a drive, a vacuum system and a control system.

Fig. 1 – Laboratory setup for wet salting of meat raw materials Ya5-FMS

The water-holding capacity was determined according to Grau and Hamm [26].

To determine the shear stress [27], the standard measuring functions of the electromechanical universal testing machine SANS CMT2503 manufactured by Shenzhen SANS Testing Co. Ltd. (PRC) were used.

Also, dial scales RN-3Ts3U and glass thermometer TTP 4 260/103 0+100C/1C were used to perform the experiments.

Results and discussion. It is known that the duration of salting of raw mkeats depends on its type and quality characteristics, morphological composition, pH, degree of autolysis, mass and shape of meat cuts, quantity, quality and temperature of brine, as well as on the efficiency of the equipment used [28]. The stable effect of the curing brine contributes to a better, more uniform coloring of the meats, however, the consequence of their massaging may be lightening due to the reduction in the time of action on the fatty tissue during vacuuming. Therefore, a more effective method is the penetration of curing substances in the case of using pulsating vacuum generation systems. This has been confirmed by experiment.

The effect of pulsating vacuum on the rate of hydro-mechanical processing of raw meats and on the quality indicators of the finished product was studied on the laboratory massager Ya5-FMS. The results of the studies are given in Tables 1–3 and Figures 2–4.

Таблиця 1

Change in the mass raw meats after holding in a massager under vacuum and under the action of pulsating vacuum depending on the processing time

Processing modes	Processing duration, min								
	60			90			120		
	Mass of cut, g			Mass of cut, g			Mass of cut, g		
	before processing	after processing	%	before processing	after processing	%	before processing	after processing	%
Vacuum	1340	1660	124	1485	2420	160	1450	2330	158
Pulsating vacuum	1420	2010	141	1640	2510	163	1100	1650	160
Control (without vacuum)	1220	1450	119	1150	1400	122	1180	1530	130

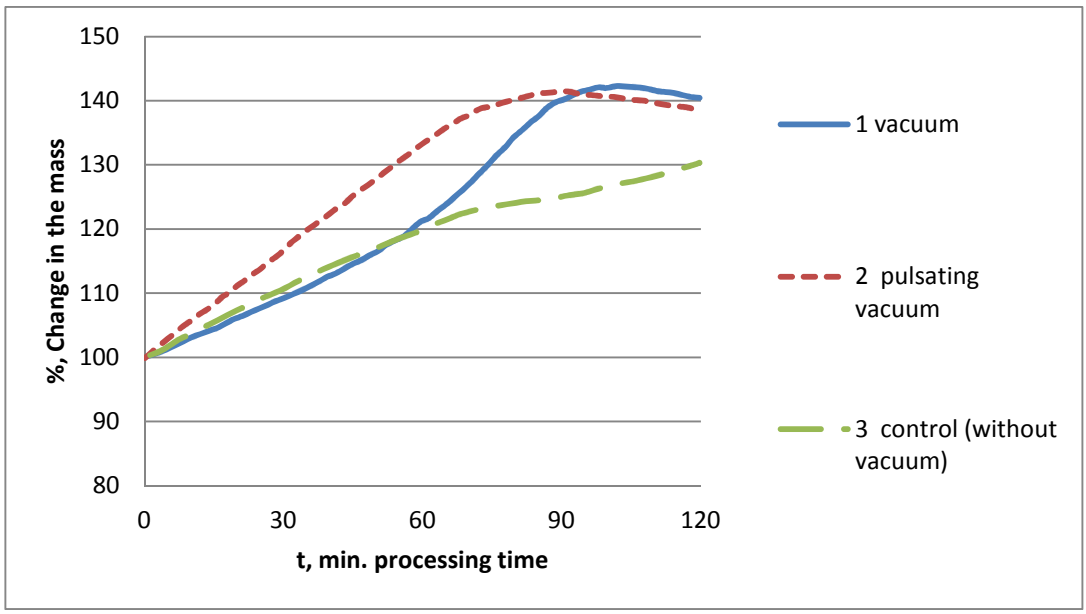

Fig. 2 – Change in the mass of raw meats after holding in a massager under vacuum and under the action of a pulsating vacuum depending on the processing time

Table 2

Change in the NaCl content, % in the finished product after holding in a massager under vacuum and under the action of a pulsating vacuum depending on the processing time

Processing modes	Processing duration, min		
	60	90	120
Vacuum	1. 27	1. 76	1. 79
Pulsating vacuum	1. 43	2. 0	2. 1
Control (without vacuum)	0. 78	0. 90	0. 93

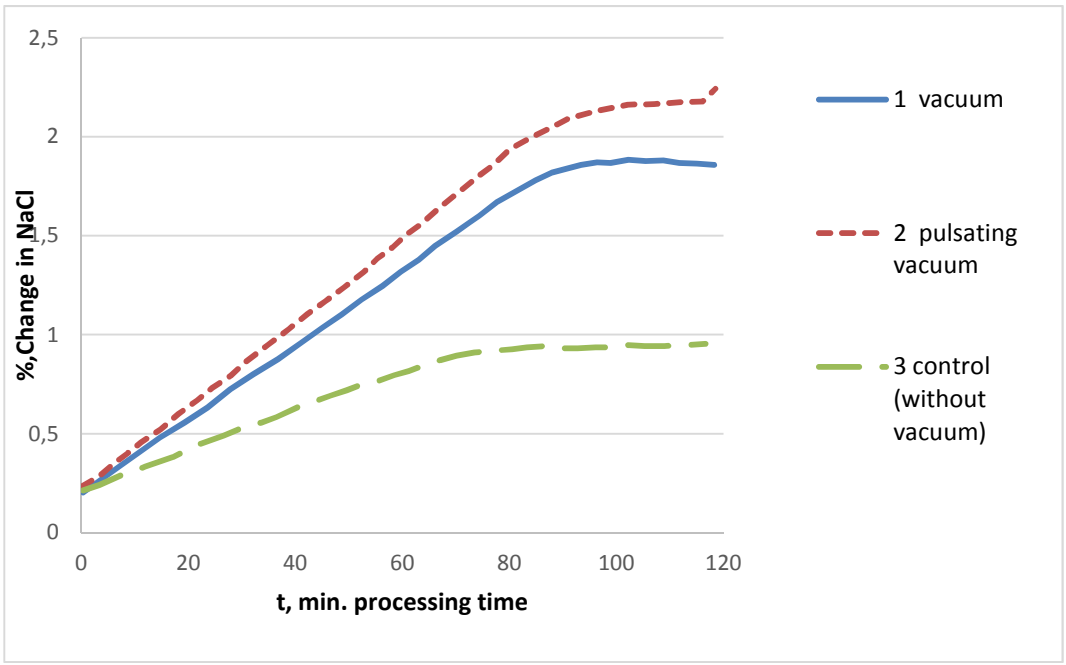

Fig. 3 – Change in NaCl content in the finished product after holding in a massager under vacuum and under the action of a pulsating vacuum depending on the processing time

Table 3

Shear stress of the finished product after holding in a massager under vacuum and under the action of a pulsating vacuum depending on the processing time (1 – vacuum, 2 – pulsating vacuum, 3 – control, without vacuum)

Parameters	Processing duration, min								
	60			90			120		
	1	2	3	1	2	3	1	2	3
Shear work, J/m^2	3.11 × 10^5	2. 28 × 10^5	3.48 × 10^5	1.54 × 10^5	1.24 × 10^5	2. 66 × 10^5	1.44 × 10^5	1.21 × 10^5	2. 58 × 10^5
Shear stress, N/m^2	1744	1570	2592	1244	980	2090	1229	920	1927
Shear force, N	21×10^2	17.5 × 10^2	29.4 × 10^2	14×10^2	10. 3 × 10^2	22.9 × 10^2	12.9 × 10^2	10.2 × 10^2	21.7 × 10^2

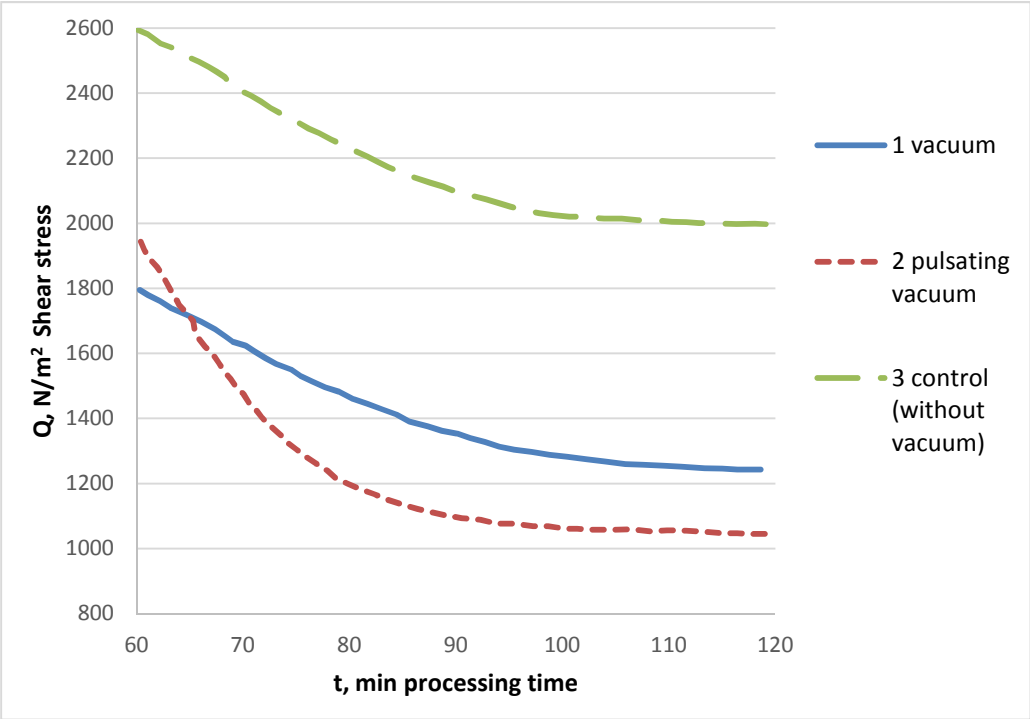

Fig. 4 – Shear stress of the finished product after holding in a massager under vacuum and under the action of a pulsating vacuum depending on the processing time

Thus, the duration of salting of raw meats depends on the type of product, quality characteristics of raw materials, morphological composition, pH, degree of autolysis, weight and shape of meat pieces, quantity, quality and temperature of brine, equipment used, etc. In addition, stable penetration of injection brine contributes to better, more uniform coloring. During hydro-mechanical processing, lighter color of meats is observed, since vacuuming reduces the time of oxygen exposure to lean tissue, and the result is a stable color during salting and the absence of air pockets in the finished product. Even more effective penetration of curing ingredients is achieved by using a pulsating vacuum, in which the processed meat raw materials are exposed to alternating loads: atmospheric pressure – vacuum. The research results show that an increase in the intensity of hydro-mechanical processing of meat raw materials causes corresponding changes in the structure of muscle fibers – their swelling, the occurrence or increase of transverse – slit integrity violations, disruption of membrane structures, loosening and swelling of myofibril proteins. All of the above indicates that the use of pulsating vacuum and drum cooling not only improves, but also significantly accelerates the process of wet salting of meat raw materials in the production of ham-like products. Therefore, the work carried out within the reporting period, namely the refinement of the design of massagers with a cooling jacket regarding the possibility of using pulsating vacuum, for which the automatic control system of massagers has been modernized, should be continued further.

The results of the studies may well serve as confirmation of the opinion of the authors [29] that the combination of modern technological methods, involving the use of complex multi-component brines, effective hydro-

mechanical processing modes and the corresponding technological equipment (devices for the preparation, supply and purification of brine, needle injectors and meat massagers) makes it possible to produce meat delicacies, including those of beef, with a good yield, stable sensorial characteristics and high nutritional value.

Conclusion and prospects for further research. The use of vacuuming in general and pulsating vacuuming in particular promotes intensifying the process of wet salting of raw meats in the production of salted meat and ham products. Therefore, the use of massagers with cooling and a pulsating vacuum system is an optimal design solution in terms of product quality and acceptable production profitability for meat processing plants.

The information obtained as a result of the experiments may be used for the development of new machines for massaging / tumbling raw meats and technical enhancing of the modes of implementation of the specified process, which will contribute in equipping meat processing plants with progressive efficient specialized equipment, the majority of which is now imported.

It seems appropriate to focus further research on a comprehensive study of the process of hydro-mechanical processing of raw meats in the entire set of its constituent technological operations: tenderization, needle injection and massaging/tumbling in order to determine rational processing modes that ensure excellent sensorial traits of the finished product and an output acceptable in terms of technology and profitability.

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ГІДРОМЕХАНІЧНЕ ОБРОБЛЕННЯ СИРОВИНИ З ЯЛОВИЧИНИ ШЛЯХОМ МАСУВАННЯ: ТЕОРЕТИЧНІ ЗАСАДИ ТА ПРАКТИЧНІ ПІДХОДИ

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Анотація. *Удосконалення обладнання для гідромеханічного оброблення м'ясної сировини є важливим і в сенсі забезпечення належної рентабельності виробництва, і в сенсі забезпечення споживачів цінною білковою м'ясною продукцією відмінного смаку. Соління м'ясної сировини, що належить до гідромеханічної обробки, є складним комплексним процесом масообміну, перетворень білкових та інших речовин, зміни вологоутримувальної здатності м'яса, зміни його мікроструктури та ін. Існують різні підходи до машинно-апаратурного оформлення та технологічних режимів гідромеханічного оброблення м'ясної сировини. Масажери/тумблери м'яса, що застосовуються в промисловості, забезпечують пристроями охолодження та вакуумування робочої порожнини. Активні дослідження ведуться щодо визначання раціональної тривалості роботи/вистою при обробленні сировини в барабані. Для яловичини рекомендують застосовувати режим чергування роботи тривалістю 30 хв та вистою тривалістю 30 хв впродовж 8 – 12 год, а також інші режими. Мета статті – викласти та логічно обґрунтувати результати досліджень масування обробки м'я-*

сної сировини в барабані масажера за різних режимів технологічного оброблення. Масування м'ясної сировини здійснювали за допомогою лабораторної установки для мокрого посолу м'ясної сировини (барабанного масажера) Я5-ФМС власної розробки. Реологічні характеристики визначали за допомогою універсальної електромеханічної випробувальної машини SANS CMT2503. Тривалість посолу м'ясної сировини залежить від її виду та характеристик якості, морфологічного складу, pH, ступеня автолізу, маси та форми відрубів м'яса, кількості, якості та температури розсолу, а також від ефективності обладнання, що застосовується. Ефективніше проникнення посолювальних інгредієнтів досягається завдяки застосуванню пульсуючого вакуумування, коли оброблювана м'ясна сировина перебуває під впливом знакозмінних навантажень: атмосферний тиск — вакуум. Збільшення інтенсивності гідромеханічного оброблення м'ясної сировини спричиняє відповідні зміни у структурі м'язових волокон – їх набухання, виникнення чи збільшення поперечно – щілинних порушень цілісності, порушення мембранних структур, розпушування та набухання міофібрилярних білків. Застосування пульсуючого вакууму і охолодження барабана не тільки покращує, але і значно прискорює процес вологого посолу м'ясної сировини при виробництві шинкових виробів. Вакуумування взагалі та пульсуюче вакуумування зокрема сприяють інтенсифікації процесу вологого соління м'ясної сировини. Тому застосування масажерів з охолодженням та системою забезпечення пульсуючого вакууму є оптимальним конструктивним рішенням у сенсі належної якості продукції та прийнятної для м'ясопереробних підприємств рентабельності виробництва.

Ключові слова: м’ясна сировина, розсіл, соління, м’якшення, вакуумування.

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