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PHYSICO-TECHNICAL PRINCIPLES OF ABATTOIR PROCESSES IN HANDLING LIVESTOCK AND POUNTRY BIRDS

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In processing the meat of stock and poultry birds in meat-packing houses the most laborious and specific work is that performed in the abattoir; these procedures include removing and treating the green hides, skins and pelts, the removal of bristles, hair and feathering, and the treatment of the intestines and by-products.

It is known that the commercial appearance, yield and quality of the produce is significantly affected by the quality of the above-mentioned operations, thus a minute study of their technology and physio-chemical and biochemical principles is indispensible for the rational utilization of all opportunities for the perfection of the handling of stock and poultry in abattoirs.

Technologically, abattoir treatment consists of siding and cutting up the carcases following, in the main, natural boundaries.

According to their functional features these processes may be subdivided into mechanical and heat processes; the first, being irreversible, call for a detailed study to ensure best quality and yield quotations upon their mass introduction. This is all the more important if we remember that animal raw materials are expensive, and that all the expenditures connected with their handling comprise but 2 to 5 per cent of their net costs. Lowered grades of the end-products, as well as the conversion of foodstuffs to technical substances as a result of unqualified handling in abattoir departments are factors greatly detrimental to the national economy.

Heat processes in abattoir treatment of stock and poultry are in the main auxiliary; naturally, they call for some increase in power expenditures when treating raw materials. However, it should be borne in mind some processes (e.g. scalding, semi-scalding) lead to an insignificant, and at times even noticeable deterioration of the products (the hides, bristles, feathers).

Thus, a study of the mechanism of separate operations and technological processes in slaughter-houses is of industrial importance, and packing house employees, as well as scientific workers, should make a detailed examination of these operations and procedures.

There is to date no literature, neither Soviet nor foreign, that dwells in sufficient detail on the physico-technical and anatomical-histological aspects of abattoir processes in handling livestock and poultry birds. The existing works are devoted either to isolated problems, or to descriptions, without analyzing or examining the kinetics and interrelationships of these processes.

The aim of the present paper was to sum up the practice of production workers and researchers in the meat and allied branches of industry, and on the basis of such data to substantiate, from the physico-technical viewpoint, the mechanical processes involved in the abattoir treatment of stock and poultry.

The parting of the hide from the carcase is connected with the destruction of the subcutaneous layer that connects the skin proper with the surface fascia of the fibrous base. This base is a multi-chamber sheathing with a complex inner structure, the separate chambers being filled out with muscles. One surface of this sheathing is in contact with the hide, the other is securely attached to the skeletal framework (A. Klimov).

The surface fascia, over its greater area of contact, is attached to the derm by means of a labile, albeit verypliant, subcutaneous layer. However, in some points the surface fascia directly approaches the derm to which its firmly attached. The hide is thus easily separated from the surface fascia only in the places where they are connected by the porous subcutaneous layer.

That part of the muscles that is enveloped by deep-lying fasciae and lies directly under the surface fascia will further, for brevity, be simply denoted as "the underlying layers".

All skinning methods may be divided into mechanical, heat and chemical processes, according to the manner in which the subcutaneous layer is treated.

Mechanical methods of taking off the hide are the processes where the subcutaneous layer is destroyed by rupturing, cutting, twisting and displacement, or by combinations of such procedures. The power needed for mechanically destroying the subcutaneous layer may be applied by various means; 1) by an external source through stretching (peeling) the hide; 2) by forcing between the hide and the surface fascia either a wedge, or blades, or a high-speed revolving wedge-sectioned bent rod (V.V.Anufriyev), etc.; 3) by pumping compressed air under the hide, or an inert gas (pneumo-skinning), water, brine (hydro-skinning) or a jet of water or brine (jet-skinning).

When skinning is performed by cutting the subcutaneous layer one or two blades may be used. In the latter case preliminary stretching of the subcutaneous layer is not necessary - it is destroyed as a result of local tension. In the first case the subcutaneous layer is cut with a knife, the blade of which is slipped, without much pressure, along the tightly stretched subcutaneous layer (this preliminary stretching is condusive to good cutting and does not call for great cutting efforts).

The heat method of taking off the hide is understood as the destruction of the subcutaneous layer by cauterizing it with a thin red-hot wire (Newhas) or by its liquification through selective heating (Fyodorov, Rogov).

Chemical methods are those in which a fast-acting chemical agent is forced under the hide to destroy the subcutaneous layer.

In the period of mass slaughter operations the most widely used skinning method is the rupture of the subcutaneous layer by means of stretching and pulling the hide and the carcase. In this procedure the stretching force needed to destroy the subcutaneous layer is passed from the hide through the subcutaneous layer to the underlying layers; thus a force chain is established, where the break, of course, must occur in the weakest link. This link is comprised of the underlying layers, as is demonstrated on a table compiled by engineer K.D. Sinitzin (see page 3), although normally the break really occurs in the subcutaneous layer.

The good skinning results attained in the subcutaneous layer, which is stronger than the underlying layers, are explained by the construction of the multi-chamber sheath (the fibrous base). In this sheath the load that falls to the entire perimeter of parting is passed in one or another form from the surface fascia to the deep-lying fascia and to the numerous partitions branching from it. The muscular tissue filling the chambers facilitate a more or less uniform loading of the chambers and the absorption of part of the load from adjacent partitions.

However, when this method of skinning is applied, the lesions and bruises that may possibly occur on the surface fascia become very important (V. Volfertz). They result in the limitation of the number of intermediate partitions that take the skinning load in the given area, and then the weakest point in the power chain becomes the place where the surface fascia is attached to the underlying layers.

Naturally, not every lesion, score or bruise of the surface fascia leads to the snatching out of meat and fat, i.e. to the removal of the hide along the underlying layers. The minimum linear dimension of a lesion along the skinning line that may lead to a disturbance of the normal skinning process may be defined by conditions of equal tensile strength.

TABLE OF MEAN INDICES FOR TENSILE STRENGTHS OF FORCE CHAIN ELEMENTS IN SKINNING SMALL HORNED ANIMALS (AT THE RATE OF V = 6 m/min.).

FACTOR	Tensile Stress (kg/cm)				
	1	2	3	4	5
1. Strength of surface fascia	2.12	1.91	1.84	1.90	2.35
2. Strength of subcutaneous layer during skinning	1.41	1.14	1.15	1.26	2.08
3. Strength of underlying layers when separating it from surface fascia	1.22	0.79	0.75	0.69	0.96

Note to Table: The condition of the livestock greatly affects the strength of the underlying layers and the subcutaneous layer; the fatter the animals, the lesser the strength of these layers.

In removing the hide the skinning angle α /fig.1/ is of essential value; the energy expended on parting the hide from the carcase equals:

$$W = 2\ Pa \cos^2 \frac{\alpha}{2}$$

where P is the tension of the hide in kg, a - the opening route in cm. For a case where the parameter of the parting line b = 1 cm and a = 1 cm, W = ω - the specific power of destruction of the subcutaneous layer in kg.cm/cm^2; then:

$$P = \frac{\omega}{2 \cos^2 \frac{\alpha}{2}} \qquad (1)$$

The application of this formula calls for the establishment of the dependence of ω on the other parameters of the process.

If the destruction of the subcutaneous layer as an elastic partition is only the result of its rupture, then, at any value of α (the other parameters being constant) ω = constant = 2 P_o, where P_o is the tensile strength at the rupture point for $\alpha = 0°$.

In this case the tension of the hide when it is taken off by tearing the subcutaneous layer may be defined, depending on α and P_o, by the following formula:

$$P\alpha = \frac{P_o}{\cos^2 \frac{\alpha}{2}} \qquad (2)$$

Fig. 2 is a depiction of the graphic functions of $P\alpha$, where curve I is theoretical, plotted against formula (2) for $P_o = 0{,}2$; curve 2 is composed of the values of $P\alpha$ for tearing friction tape from a roll; curve 3 is plotted against the values of $P\alpha$ for rabbit skinning; curve 4 - for sheep skinning. Fig. 2 makes it clear that the theoretical and real curves are very similar and that they are a convincing substantiation of the function expressed by formula (2).

Although there is some literature on the effect of the angle of skinning on the value of the tension of the hide, we have not found any on the effect of the skinning rate on this tension. The effect of the skinning rate on the tensile strength of the hide in small drops in speed is not easily noticed. In order to reveal this dependency at significant drops in speed we have, like K.D. Sinitzin, employed the "cascade" method for defining the effect of skinning rates on the tensile strength of the hide.

A rabbit skin was split with a knife along the white line and the spinal column; half of this skin was taken off at a rate of 0.1 m/min ($\alpha = 0^o$), the other half at the rate of 1 m/min; in a second case the figures were 1 and 10 m/min, in a third - 10 and 100 m/min, and in a fourth - 0.1 and 100 m/min.

The dependence of the tension of the hide on the rate of its removal obtained by us in our experiments is expressed by a formula that is similar to the Busse-Zhurkov formula that is true for many fibrous polymers.

$$V = B\ell\ o,\ P_o \qquad (3)$$

where V is the skinning rate in meters per minute, P_o - the specific tension of the hide in kg/cm for $\alpha = 0^o$, α_o and B are constant factors that depend on the strength and temperature of the layer that is being destroyed, ℓ is the base of natural logarithms.

Apparently, the process of rupturing the subcutaneous layer is the phenomenon that is called fatigue in engineering; its occurrence is general and is observed in all substances.

The experiments performed in the All-Union Meat Industry Research Institute made it possible to derive a mean value for P_o in skinning cattle at a rate of V = 6 m/min. These values are: P_o = 2.8 kg/cm for skinning bulls, P_o = 1.8 kg/cm for skinning cows, and P_o = 1.2 kg/cm for skinning calves.

The strength range of the subcutaneous layer is quite wide, although in all cases the dependence of the strength on the skinning rate is defined by formula (3), for all breeds.

In examining the process of skinning, various authors speak of the effect of the rate on the quality of the process, but they do not offer any explanation for this phenomenon. Let us briefly consider its mechanism.

In the skinning process the subcutaneous layer is deformed at a rate that corresponds to the skinning rate, while the surface fascia and the underlying layers are deformed more slowly. Under equal conditions the deformation rate of the subcutaneous layer is lower than that of the surface fascia. However, the subcutaneous layer is greatly fortified during the skinning process as a result of a great increase of deformation, while this does not occur in the surface fascia.

This occurrence leads to a rupture of the surface fascia, to the snatching out of meat and fat, to the deterioration of the quality of the skinning process.

Consequently, the ultimately permissible rate of skinning is one under which the temporary strength of the subcutaneous layer is equal to the strength of the surface fascia that corresponds to the skinning conditions.

Naturally, lower skinning rates give satisfactory results, while rates that exceed the permissible limit give unsatisfactory results.

The tensile forces defined by the stretching of the hide depend on both the skinning rate and the skinning angle.

We shall now examine the method employed for defining the ultimate rate permissible in taking off the hide.

On the diagram P&gV, the deviation in the strength of the subcutaneous layer depending on the rate of deformation at $\alpha = 0^o$, is defined by a straight line a - c. In taking off the hide, when $\alpha > 0^o$, - the straight lines will lie above the line a - b.

In order to plot a curve that will correspond to the strength of the surface fascia, we shall suppose that the rate of deformation of this fascia deviates very little during the skinning process, and, basing ourselves on this, we shall consider the strength value to be constant (the line c - d). The points of interception of the straight line c - d with the lines a - b, a_1-c_1, etc., that correspond to the changes of P at various values of α result in V_n - the ultimately permissible skinning rate. For sheep skinning the numerical values of V_n are:

α	= 0°	30°	45°	60°
V_m	= 12.0	7.0	3.6	1.6 m/min.

It is thus clear that the existing methods employed in skinning increase the strength of the subcutaneous layer as a result of its fast deformation, while the strength of the other elements of this force chain are but little altered.

If the strength of the surface fascia and of the underlying layers are correspondingly increased (naturally or artificially) - the ultimately permissible rate of skinning may also be increased, as was proved at VNIIMP (the All-Union Meat Industry Research Institute) in the skinning of cooled carcases.

Removing Hair and Bristles. In meat-packing houses hair is removed from hairy by-products on a mass scale. Hairs are a horny, solid, but elastic and pliable filament comprised of epidermis cells. They are dispersed on the hide separately or in groups. Hair retentivity, depending on the animal's breed, sex, age, the season of the year and location, is within 20 to 60 g per hair at a rate of removal equal to 5 - 10 m/min for cattle. Scalding the hide with water at 60°C for 4 - 5 minutes lowers the retentivity to 5 - 8 g (at the same rate of removal), so that it may be removed by rubbing the pieces under treatment against each other. Hair retentivity is also noticeably lowered by sonic treatment (Friedman et al).

The removal of hair from woolly by-products is performed in centrifugal machines, where the reciprocal pressure of the separate pieces is sufficient for removing hair from products preliminarily treated by heat.

The Bristle and Hair Coat of the Hog. Morphologically the structure of hair and bristles are in the main similar. These appendages may be sub-divided into three groups, depending on the thickness of the hairs or bristles: large, with a diameter of 250 to 300 microns; medium - 200 to 250 microns; small - 150 to 200 microns. The retentivity of bristles while they are being pulled out of the hide of a freshly slaughtered hog at the rate of approximately 10 m/min respectively equals 500 - 300 - 200 g per bristle. Heat treatment lowers the retentivity of bristles 8 to 10 times. Sonic treatment also lowers bristle retentivity. The dependence of the retentivity on the pulling rate has been proved experimentally; it may be defined by formula (3), where P_0 is the retentivity, V - the rate of removal in m/min and α_0 and B are constant factors.

The plumage of poultry birds must be completely removed in the abattoir department. The plumage is made up of separate feathers comprised of a shaft and fan. The lower section of the shaft is a hollow cylinder called the nib. The nib lies in a pocket of the skin and is connected to it by means of follicles. The skin-pocket is a sheath that, together with the follicles creates the retentive force that must be overcome when plucking the feathers. Evidently, the greater the diameter of the nib and the deeper it lies in the skin - the greater the retentivity. The skin of birds is thin, and owing to a strongly developed subcutaneous layer, it is very mobile. The weakness of this skin and its mobility make it impossible to pluck feathers in bunches.

The retentivity of poultry plumage after the birds have been butchered may be sub-divided into three groups, the plucking rate being 5 - 10 m/min: 1/ - large feathers, retentivity lying within the range of 1 to 10 kg; 2/ - medium feathers, retentivity 0.1 to 1 kg, and 3/ - small feathers, retntivity less than 0.1 kg. Heat treatment lowers the retentivity 3 to 5 times; the retentivity of feathers with nibs lying just below the surface of the skin is greatly lowered, while for feathers with deep-lying nibs the retentivity changes but little.

When the birds are cooled after heat treatment the retentivity of their feathering is restored, sooner for the feathers with nibs lying near the surface of the skin and slower for the feathers with deep-lying nibs.

An analysis of data on the restoration of feather retentivity after heat treatment substantiates the consecutive order of the various processes involved in handling butchered poultry birds and shows that feather plucking should be completed within fifteen minutes after heat treatment. Later plucking results in unsatisfactory quality indices (Tikhomirov A.E.).

The method selected for the removal of hairs, bristles or feathers depends on the physical dimensions of the objects to be withdrawn and on their retentivity. The plucking is performed by means of gripping the object either on one or two sides. For plucking with a two-faced clamp, roller machines with smooth or rifled rolls are employed. Withdrawal by means of unilateral contact with the working part consists of the reciprocal rubbing of the separate parts of the produce under treatment, whereby the greatest force of friction is ensured; it is also performed by means of the mutual displacement of the produce and the working part (scrapers, fingers, blades, combs, etc.). The working surfaces of these parts and normal power values ensure a fixed quality of the process. In all cases of withdrawal of bristles, hairs, and feathers the pulling force that arises on the surface of contact should be more or less equal to the sum of the retentivity, friction, inertia and other forces accompanying this process and manifested during the operation of the working parts on the product, i.e.

$$F \Rightarrow (F_y + \Sigma F_c) \quad z$$

where F is the pulling force,

F_y - the retentivity of the article being withdrawn,

ΣF_c - the sum of resistances per unit of withdrawn objects

Z - the number of simultaneously withdrawn units.

In selecting the manner of removing hair, bristles and feathers and the material for the working parts of such machines, all requirements for ensuring produce quality and yield should be adhered to; the forces arising in the surface layers of the product must not exceed their strength.

The above descriptions of the mechanisms of the phenomena and the analysis of the processes of removing hair, bristles and feathers make it clear that:

1. The elements to be removed are securely fixed in the skin and their retentive power depends both on the degree of the coherence of the root (nib) and its nutritive organs and on the gripping strength of the enveloping sheath, as well as on the plucking rate;

2. Plucking is effected owing to the rupture of links on single applications of external loads;

3. Power expenditures on removing hair, bristles and feathers depend on the retentivity, depth of roots and pliancy of the skin; these expenditures may be decreased if retentivity be lowered before plucking;

4. If the skin is weak, while the retentivity of the plucked objects is high - these objects should be plucked one by one; bunch plucking may damage the skin. In such cases a brace is applied between the separate elements;

5. The method of plucking depends on the physical dimensions and retentivity of the plucked objects; a unilateral or two-faced clamp or working contact may be used;

6. The pull that arises on the contact surface of the working organ and the plucked element should be great enough to overcome the resistances that appear when bristles, hairs or feathers are being withdrawn; however, the construction, manufacture, specific pressure and performance of the working organs executing the plucking operations should not deteriorate the quality of the hide and of the plucked object.

Hair, bristle and feather plucking is performed in roller, scraper, and centrifuge type machines, or in impact machines.

The following requirements must be met in the construction of rolling machines:

1/. The force of pressure of the rolls R should be great enough for creating a traction that exceeds the sum of all the resistances:

$$R = \frac{K.Z.F_y}{2\mu}$$

where F_y is the retentive force,

Z - the number of simultaneously plucked units,

μ - the coefficient of friction arising at the moment of withdrawal between the working surface and the plucked element,

K - the factor that covers the resistance accompanying plucking.

2/. The diameter of the roller D is based on its durability; however, for proper conditions of tightening

$$D \geqq /20 \div 25/\, d, \quad D \geqq 1.2\ell$$

where D is the diameter of the plucked element, ℓ - the minimum length of the plucked element corresponding to its strength. In constructing unilateral contact machines the following conditions must be adhered to: the traction arising on the surface of contact must be great enough to overcome all the resistances that accompany plucking. As the force of traction is also the force of friction, the normal force inducing it should be

$$R = \frac{K.Z\,(F_y + \sum F_c)}{\mu - \mu_1}$$

where μ_1 is the coefficient of the sliding friction of the plucked element and the surface of the carcase.

It is evident that when $\mu = \mu_1$ such principles of plucking are not feasible. It follows that the construction of a machine with a unilateral contact of the working and plucked elements is possible only if $\mu > \mu_1$. The force R may be induced by the weight of the carcase, bird, or piece of produce under treatment, by centrifugal force or by the resilience of the working organ, the pressure of the clamping spring, etc.

In constructing impact machines it should be taken into account that the energy lost by the impact organ (or scourge) should be enough to eliminate and cover the power expenditures that accompany the plucking process, i.e.

$$\frac{G}{2g}\,(V_h^2 - V_k^2) = Z\,(A + \sum An)$$

where G is the weight of the working part of the scourge, g - the acceleration of terrestial gravity, V_h - the speed of the gravitational centre of the working part of the scourge before impact, V_k - the same after impact, A - the energy spent on the plucking process, and $\sum A_n$ - the sum of the separate forms of energy losses that accompany the plucking process.

SUMMARY

1. The processes involved in abattoir handling of livestock and poultry birds (skinning, plucking bristles, hair and feathers) are chiefly accounted for by the break of links in singular applications of external loads.

2. The forces of resistance to rupture of the subcutaneous layer and the retentivity displayed in plucking bristles, hairs and feathers depend on the nature of the links, the age, sex and fatness of the animal, the surface area, the breed, the season of the year, and also on the preliminary treatment and speed of withdrawal or deformation.

The dependence of the forces of resistance on the rate of deformation are in the main characterized by the Busse-Zhurkov formula, which is true for many fibrous polymers, namely:

$$V = B\ell^{ap}$$

3. The existing industrial method of preliminary heat treatment before plucking bristles, hairs and feathers greatly lowers the retentivity and the power expenditure on plucking, a factor that facilitates the organization of such procedures on a mass scale. However, heat treatment noticeably lowers the quality of the produce. Physical methods of preliminary treatment of butchered animals and birds that will not lower the quality of the products as heat treatment does should be found in the future.

4. Taking off the hide by the method of breaking links results in high quality skinning operations when the parting of the hide from the carcase is performed in the subcutaneous layer, and if the ultimately permissible skinning rate for the given conditions is not exceeded. This rate, as was pointed out above, may be accelerated by means of artificial or natural strengthening.

5. The tension of the hide while it is being taken off by the links-breaking method also depends on the skinning angle, this dependence being expressed by the following formula:-

$$P_{\alpha} = P_o : \cos^2 \frac{\alpha}{2}$$

6. The principles on which machines for removing bristles, hair and feathers are constructed were discussed above; these principles are the basis for expedient constructions of the working parts of machines and for establishing a consecutive order of industrial processes and future trends in the creation of continuously operating and automatic machines for removing hair, bristles and plumage.

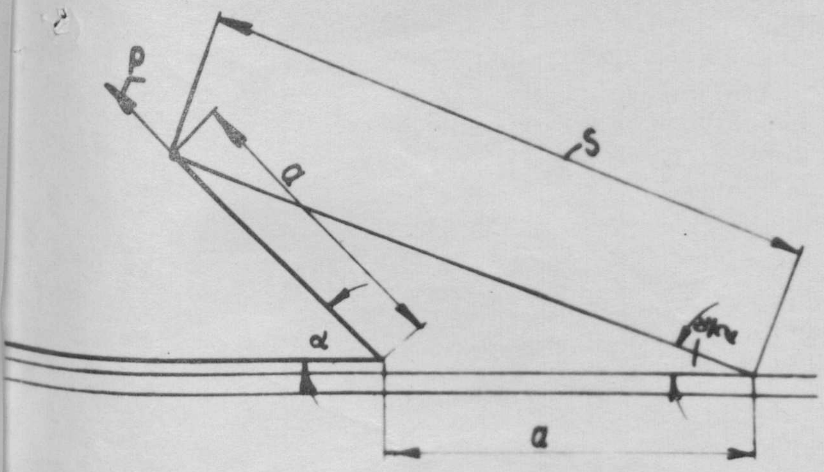
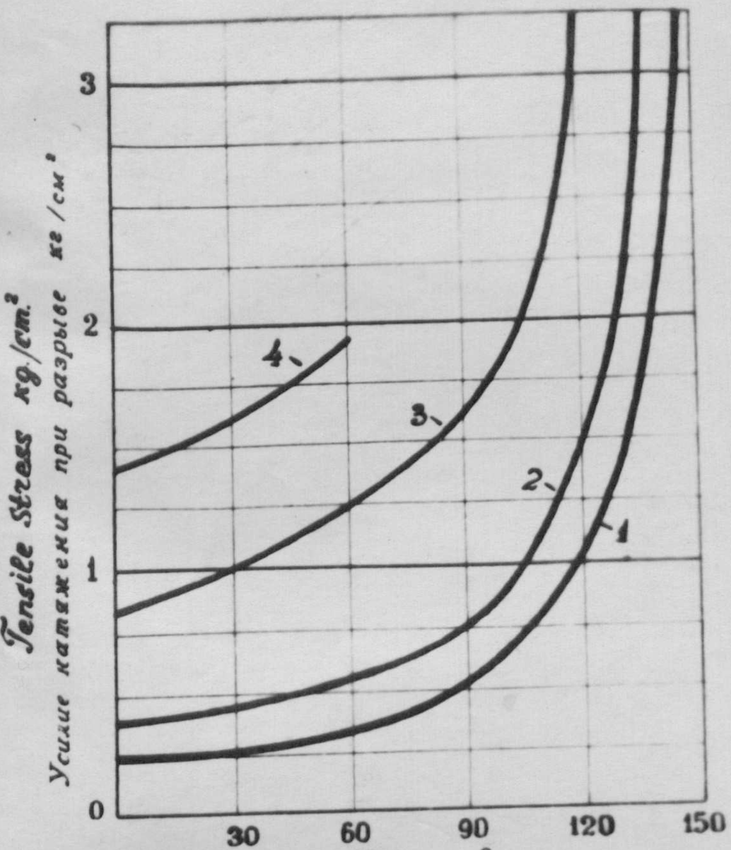


Fig. N 1



Angle α°   Угол α°
Fig. N 2   Фиг. 2

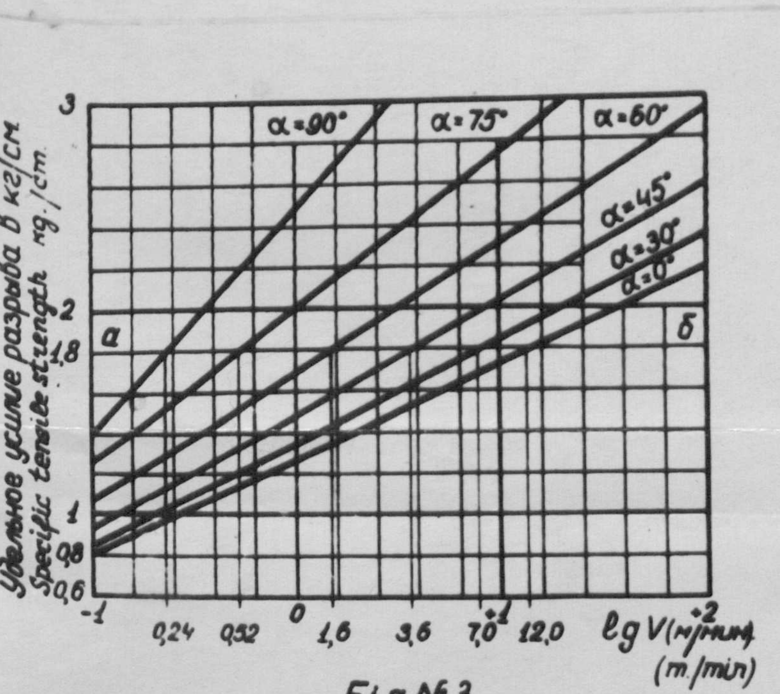


Fig N:3.