Selection of criteria for achieving heat and moisture resistance of plucker finger of poultry equipment

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Abstract. The paper presents the results of studies to increase the life of plucker fingers of poultry farms operating under cyclic deformations in an environment of elevated temperatures and humidity. The limiting indicators of the rubber base of different nature on the elastic-strength indicators of vulcanizes are established. The defining criteria of running life are identified: fatigue resistance to dynamic loads and resistance to thermal-oxidative ageing in a vapour environment. The choice of the nature of rubber according to the criterion of resistance of vulcanizes to thermal ageing was made. Limitations of vulcanizes based on single polyisoprene have been proved due to their instability to thermooxidative ageing. The composition of heat-and-moisture-resistant vulcanizes has been developed. The required level of elastic-strength characteristics before and after wet thermal ageing provided: the combination of polybutadiene and polyisoprene and combination of ingredients. The proposed method of regulating the hardness and modulus of the vulcanizes change in the content accelerator high activity of thiuram disulphide. The effect of thiuram sulfdide additives on the kinetics of vulcanization of rubber mixtures and elastic-strength parameters of vulcanizes was studied. The molecular characteristics of the obtained vulcanizes are given. A solution was found to replace foreign-made products. A method is proposed for regulating the hardness and modulus of vulcanizes by changing the content of a high-activity accelerator – thiuram sulfide. This article presents the study of the thiuram sulfide additives effect on the kinetics of vulcanization of rubber mixtures and elastic-strength parameters of vulcanizes. The solution found is to replace foreign-made products.

1. Introduction

One of the fastest-growing food industries is poultry processing. In the technological process of processing poultry meat, the primary processing includes operations of steaming and removing the feather on machines with special rotating nozzles of a cylindrical and conical shape (plucker fingers) that remove feathers and fluff from the carcasses of birds. The working conditions of such fingers are cyclic dynamic deformations in a medium of hot water vapour. Currently, a large assortment of elastic plucker fingers of foreign manufacture is widely used in poultry farms of the Russian Federation. The paper presents the results of studies to increase the lifespan of plucked fingers for poultry farms operating under conditions of cyclic deformations in an environment of elevated temperatures and humidity.
Currently, poultry farms in the Russian Federation widely use a large range of elastic plucker fingers of foreign-made production. The operating conditions of such fingers are cyclic dynamic deformations in the environment of hot water vapour. During operation, the rubber base of the fingers is subject to constant thermo-oxidative ageing, re-vulcanization against the background of washing of antioxidants by vapour condensate [1-2]. The creation of food-safe domestic plucker fingers with increased operational mileage in conditions of compression – tension deformations, vapour and thermal ageing remain relevant.

The purpose of the work was to develop prescription and technological solutions for improving the composition and technological modes of vulcanizate production in the production of plucker fingers with improved mechanical and operational characteristics.

The objectives of the study:
• to substantiate approaches to the selection of the composition and criteria for evaluating the operational properties of vulcanizates in conditions of cyclic deformation in a water vapour environment;
• to establish the effect of the polymer base nature and the ingredients of the rubber mixture on the elastic-strength indicators of vulcanizates;
• to solve the problem by prescription and technological methods.

2. Materials and methods

In order to solve the problem of creating heat-resistant rubber products as an analogue of an imported sample, a rubber mixture of the P2 composition based on 100 pts. wt. of polyisoprene (IR) was studied (Table 1) and vulcanizes based on it.

This composition had the necessary strength, elastic and dynamic characteristics [3-4]. However, in conditions of high humidity and temperature, vulcanize was quickly subjected to thermal oxidation ageing and became unusable. The mileage was one day, compared to one month for foreign-made fingers.

Table 1. Formulations of rubber mixtures based on rubbers of different nature

| Ingredients                                      | Content, phr |
|--------------------------------------------------|--------------|
| IR                                               | 100          |
| NBR                                              | -            |
| BR                                               | -            |
| Sulfur                                           | up to 1.5    |
| Sulfinamide                                      | up to 1.0    |
| Thiuram disulphide                               | up to 0.3    |
| Zinc white                                       | up to 4.0    |
| Stearic acid                                     | up to 1.0    |
| Product of condensation of a secondary aromatic amine with acetone | up to 2.0    |
| High molecular weight secondary aromatic diamine  | up to 3.0    |
| Alkylphenol-formaldehyde resin                   | up to 2.0    |
| Carbon black P-324, P-803                        | up to 40.0   |
| Carbon black N-330                               | up to 50.0   |
| Anti-scorching                                   | up to 0.1    |
| Plasticizer                                      | up to 6.0    |

Improved compositions of rubber mixtures: P6 based on nitrile butadiene rubber (NBR); P14 and PT14 based on a combination of butadiene rubber (BR) and IR in a ratio of 60/40 were developed;
rubber mixtures PT-14 additionally contained thiuram disulfide. Preparation of rubber mixtures was carried out in two stages.

Standard methods were used for studying the vulcanization characteristics of rubber compounds, elastic-strength indicators of vulcanizes, fatigue endurance, resistance to thermal ageing and resistance to aggressive environments [5-7].

3. Results and discussion
It is possible to increase the life of rubber at intensive ageing temperatures by inhibiting the destruction of the rubber base [8-9]. Based on the literature sources [10-11], it was found that vulcanizes based on 100 pts. wt. of butadiene nitrile rubbers (P6), for example, NBR, should have the highest resistance to thermal ageing (Table 1). Due to the high nonlimiting value, they provide the required elastic and strength characteristics. In contrast to vulcanizes of P2 composition based on 100 pts. wt. of IR, P6 composition retains its indicators after degradation (Figure 1). However, vulcanizes based on 100 pts. wt. of the NBR were not suitable for long-term operation when tested for fatigue resistance to cyclic deformations (Figure 2). This circumstances led to the replacement of the polymer base with a mixture of BR and IR (P14) in a ratio of 60 : 40 pts. wt. (Table 1).

The vulcanizing group is represented by vulcanization agents (natural sulfur, polymer sulfur, alkylphenol formaldehyde resin), sulfenamide vulcanization accelerator, activators (zinc white, stearic acid). By varying thiuram disulphide expected to regulate the hardness and modulus of the vulcanizates. For increasing the duration of the induction period in the composition, there is anti-scorching.

Another change was the addition of alkylphenol formaldehyde resin (APFR). The presence of APFR is aimed at increasing resistance to temperature ageing by replacing broken sulfide bonds with C–C bonds. Alkylphenol formaldehyde resin served not only as a vulcanizing agent but also as an antioxidant. The presence of APFR in the composition determines the high vulcanization temperature of rubber compounds (160°C or more). An oligomeric product of the condensation of secondary aromatic amines with acetone and a high-molecular secondary aromatic diamine was a high-molecular antioxidant resistant to washing by vapour condensate. Additionally, a plasticizer with a reduced content of polyaromatic compounds is added to the composition. For prevent reversion during vulcanization, the processing time was reduced to 9 minutes, while a degree of vulcanization of 80% is achieved.

The highest strength and elongation at break was a sample of vulcanization P14 based on a combination of BR and IR (Figure 1-3). The increased residual elongation was explained by a deliberately low degree of vulcanization (80%). When testing samples for multiple stretching, P14 based on a combination of BR and IR demonstrated better fatigue endurance indicators (2268.0 thousand cycles), which were several orders of magnitude higher than those of other vulcanizes (Figure 4).
These results are because polybutadiene has low hysteresis losses due to increased mobility of macromolecule segments. During the operation of vulcanizes in a hot environment, the macromolecules of polybutadiene are structured, while the macromolecules of polyisoprene are subject to destruction, that is, a decrease in the molecular weight. Since these processes mutually compensate for each other, there is a high dynamic endurance and resistance to thermal ageing.

### 3.1 Selection of the nature of rubbers by the criterion of resistance of vulcanizates to thermal ageing.

During thermal degradation in water vapour (90°C, 100 h), the elastic-strength characteristics of vulcanizates changed (Figure 1–3, Table 2).

The coefficients of resistance to ageing (degradation) were calculated as the ratio of elastic-strength indicators after aging to the initial indicators. The higher the coefficient of degradation in terms of strength (f) and lower in terms of residual elongation (εr), the more resistant vulcanize is to the effects of thermal ageing. For P2, P6 and P14 compositions, a decrease in elongation (ε) and residual elongation at break was observed, and for compositions P14, P2, an increase in strength was observed. This result is due to the composition of the rubber base and the achievement of the degree of vulcanization of almost 100%.

### Table 2. The effect of the rubber type on the degradation coefficients of vulcanizates

| Degradation coefficients | Compositions |
|-----------------|--------------|
|                  | P2 (IR)      | P6 (NBR) | P14 (BR/IR=60/40 pts. wt.) |
| Tensile strength (fag/f) | 0.7          | 1.1       | 1.1          |
| Elongation at break (εag/ε) | 0.7          | 0.8       | 0.7          |
| Set after break (εr ag/εr) | 0.5          | 0.2       | 0.4          |

The P6 composition was more resistant to static thermal-moisture ageing (Figure 1-3, Table 2), and the most resistant to dynamic fatigue endurance was P14 (Figure 4). The data in Figures 1-3 and Table 2 are consistent with the theoretical ideas about the ageing mechanism of vulcanizes given in the literature [9].

### 3.2 Study of the effect of thiuram sulfide additives on the kinetics of vulcanization of rubber compounds and elastic-strength indicators of a vulcanization

Samples of a finger according to the P14 recipe following the mixing and vulcanization modes defined by the technological regulations were manufactured under production conditions and then sent to the consumer. Based on the results of field tests, it was concluded that the modulus and hardness of
vulcanizes should be regulated. By changing the content of thiuram sulfides in PT-14, the hardness and modulus of vulcanizes were regulated.

The time of the induction and main periods were determined, as well as the optimum time of vulcanization at 165 C were determined based on the analysis of the kinetics of vulcanization by rheograms (Figure 5).

![Figure 5](image_url)

**Figure 5.** Rheograms of samples PT-14 with the variation of thiuram disulfide: 1 – 0.57 pts. wt.; 2 – 0.28 pts. wt.; 3 – without thiuram disulfide.

In order to increase the resistance to aging and reversion during operation in a water vapour environment, vulcanization was stopped after reaching 80 % of the crosslinking (165°C, 5.0 min).

Compared with the initial composition of P14, the addition of thiuram sulfide (PT-14) even in the presence of anti-scorching showed a reduction in the duration of the induction period and an acceleration of the main vulcanization period.

The elasticity of the sample decreased when changing the composition and vulcanization mode (Table 3). The elasticity of vulcanizes shows the amount of energy returned during elastic deformation and, consequently, the relative hysteresis losses. This vulcanization is more resistant to elastic deformation. The lower the hysteresis value, the less prone vulcanization is to crack formation [1, 14-15].

| Composition                          | Elasticity, % | Shore A hardness |
|--------------------------------------|---------------|-----------------|
| P2 (100 pts. wt. IR; thiuramsulfide; 155 °C; 15 min) | 41            | 60              |
| P6 (100 pts. wt. NBR; 155 °C; 15 min)            | 34            | 67              |
| P14 (BR/IR = 60/40 pts. wt.; 165 °C; 9 min)       | 32            | 42              |
| PT-14 (BR/IR= 60/40 pts. wt.; thiuramsulfide, 165°C; 5 min) | 34            | 61              |
| Foreign-made sample                   | 57            | 60              |

Among the proposed compositions, the highest elasticity indices were obtained from P2 (100 pts. wt. IR), hardness – P-6 (100 pts. wt. NBR).

The low elasticity and hardness of the vulcanization of the P14 composition were explained by a deliberately low degree of vulcanization.
The assessment of the stability of vulcanizes in the presence of thiuram sulfide to thermal-moisture aging was also evaluated by accelerated thermal-oxidative ageing at 90 °C in a vapour environment for 100 hours (Table 4).

The presence of thiuram sulfide in PT-14 resulted in a decrease in residual elongation ($\varepsilon_{\text{res}}$) both before and after accelerated ageing.

For vulcanizes of PT-14 composition, an increase in $P_{100}$, $P_{200}$, and $P_{300}$ modules was observed at 100, 200, and 300% elongation, maintaining strength and reducing (by 1.5 times) elongation after rupture and residual elongation (by 20-30 times), which was explained by the completion of the vulcanization process. It was found that in the process of thermal moisture degradation of vulcanizes in the absence of thiuram sulfide (P-14), the module parameters decrease. There is an optimal content of thiuram sulfide and a vulcanization mode in which the residual elongation is minimal.

| Indicators | Indicators / degradation coefficients (curing mode) |
|------------|----------------------------------------------------|
|            | P14 (165 °C; 9 min) | PT-14 (165 °C; 5 min) |
| $P_{100}$, MPa | 6.1/0.4 | 1.9/1.2 |
| $P_{200}$, MPa | 12.8/0.3 | 3.6/1.3 |
| $P_{300}$, MPa | 14.0/0.5 | 6.4/1.4 |
| $f_b$, MPa | 15.6/1.1 | 15.6/0.9 |
| $\varepsilon$, % | 852/0.7 | 583/0.7 |
| $\varepsilon_{\text{res}}$, % | 15.7/0.4 | 12/0.5 |

When studying the resistance to aggressive environments of the samples, it was found that, according to the degree of swelling in water ($\alpha$), the experimental samples P14 ($\alpha=0.9\%$) and PT14 ($\alpha=0.9\%$) were superior to the imported sample ($\alpha=7.9\%$). The rates of swelling in the organic solvent of domestic samples at 80 % degree of vulcanization practically coincided with those of imported samples.

### 4. Conclusion

Approaches to creating a recipe and methods for regulating technical parameters of heat-and-moisture resistant products – plucker fingers for poultry farms, operating under cyclic dynamic loads are substantiated. The defining criteria of running life are identified: fatigue resistance to dynamic loads and resistance to thermal-oxidative ageing in a vapour environment. The necessary level of elastic-strength indicators both before and after thermal-moisture degradation was provided by using following combination of ingredients:

- a combination of isoprene and polybutadiene rubbers;
- a combination of sulfur and resin vulcanizing groups; a combination of natural and polymer sulfur as a sulfur vulcanization agent and alklyphenol formaldehyde resin (APFR) as a resin vulcanization agent;
- a combination of accelerators of medium (sulfenamide) and high (thiuram sulfide) activity;
- a combination of high-molecular antioxidants resistant to leaching by vapour condensate – an oligomeric product of the condensation of the secondary aromatic amine with acetone and high-molecular secondary aromatic diamine, including a dual-purpose ingredient – APFR;
- a moderate (no more than 50 %) degree of filling of rubbers with active black carbon; a high level of vulcanization temperature of 165-180 °C.

The composition of heat-and-moisture-resistant vulcanization has been developed. A method is proposed for regulating the hardness and modulus of vulcanization by changing the content of a high-activity accelerator – thiuram sulfide. A solution for replacing foreign-made products is proposed.
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