Theoretical calculations of mechanotermic destruction process with regard to general rubber goods

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Introduction

The processing of rubber products by pyrolysis (heating to decomposition temperature without air access) has existed since the beginning of the use of rubber on an industrial scale.

The theoretical prerequisite for our idea was the high value of the viscosity of rubber products, and, therefore, a rather large value of the coefficient of friction caused by the presence of cross-links in the polymers of this class.

In 2009-2010, we created an experimental installation for the processing of automobile rubber, described in [1]. The operation of such installation has not only evidenced the undoubted prospects of the proposed method. Since the existing scientific sources do not even mention our proposed method of rubber processing, we came to the conclusion that some reference data should be collected on the composition and construction of rubbers, as well as the effect of fillers, volcanizers and other chemical agents on their properties (table 1).

Table 1. Some reference data on rubber processing.

Size, dimension	Rubber	Volcanizate	Volcanizate + C	Carbon
Density ρ, кg/m^3	1050	1200	1227	1400
Coefficient of thermal conductivity λ, W/m·К	0.130	0.167	0.248-0.293	0.85-0.91
Thermal diffusivity, $a \cdot 10^8$, m^2/sek	8.9-9.0	11.5-13.0	17-20	–

The purpose of the article.

Based on the analysis of the reference data, to calculate the amount of thermal (electrical) energy required for mechanothermal destruction of rubbers. Based on the heat balance of the process of their processing, to show the prospects of this pyrolysis method.

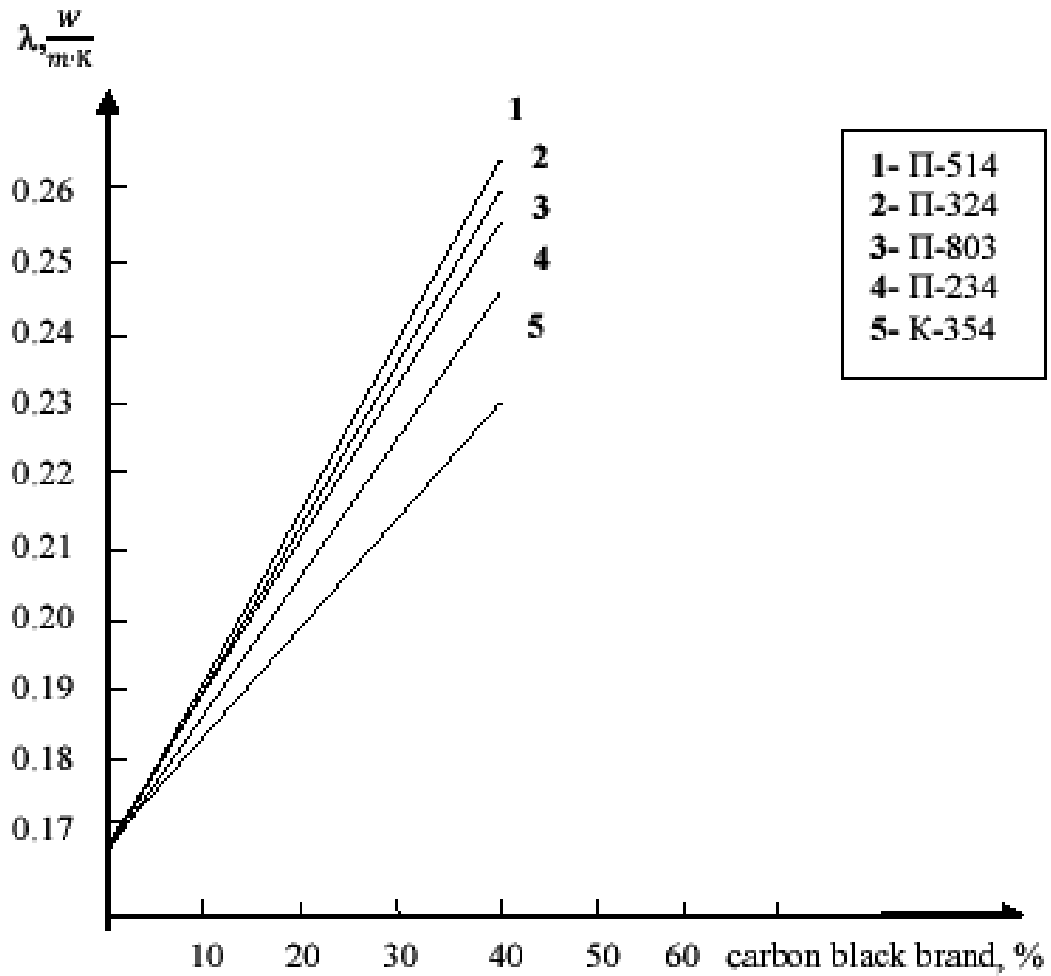
Using formula

$$\lambda_{rubber} = \lambda_0 + K_\lambda \cdot \omega$$

we calculated the changes in the coefficient of thermal conductivity of polyisoprene rubbers, depending on the content and type of carbon black used as a rubber filler, to increase the hardness of tire treads, increase their wear resistance and other useful qualities. The results are presented both as a table (table 2) and as a graph (drawing 1).

Table 2. Thermal Conductivity Values λ.

Brand of carbon black	К-354				
Mass fraction of carbon black, %	0	10	20	30	40
Coefficient of thermal conductivity λ, W/m·K	0.167	0.182	0.197	0.212	0.227
Brand of carbon black	П-234				
Mass fraction of carbon black, %	0	10	20	30	40
Coefficient of thermal conductivity λ, W/m·K	0.167	0.187	0.207	0.227	0.247
Brand of carbon black	П-324				
Mass fraction of carbon black, %	0	10	20	30	40
Coefficient of thermal conductivity λ, W/m·K	0.167	0.190	0.212	0.235	0.257
Brand of carbon black	П-514				
Mass fraction of carbon black, %	0	10	20	30	40
Coefficient of thermal conductivity λ, W/m·K	0.167	0.191	0.214	0.238	0.261
Brand of carbon black	П-803				
Mass fraction of carbon black, %	0	10	20	30	40
Coefficient of thermal conductivity λ, W/m·K	0.167	0.188	0.208	0.229	0.249



Drawing1. Graphic dependence of the coefficient of thermal conductivity on the content and brand of carbon black.

As a result of the analysis of the obtained data, we calculated the difference in the values of the thermal conductivity coefficient. For some types of rubbers, the difference in λ values, depending on the content and brand of carbon black, can reach a maximum of 56% compated to unfilled volcanizate.

With an increase in temperature for every 100 °C, the heat capacity increases by approximately 15% .

The obtained range of heat capacity of filled rubbers is quite wide, but since values of the same order are obtained, it is possible to calculate the energy consumption necessary for processing a unit mass of rubber goods for depolymerization products.

$$W_1 = \frac{(957 \div 1495)}{1000 \cdot 3600} = (2{,}66 \cdot 10^{-4} \div 4{,}15 \cdot 10^{-4})\,[\frac{kW \cdot h}{\kappa g \cdot K}]$$

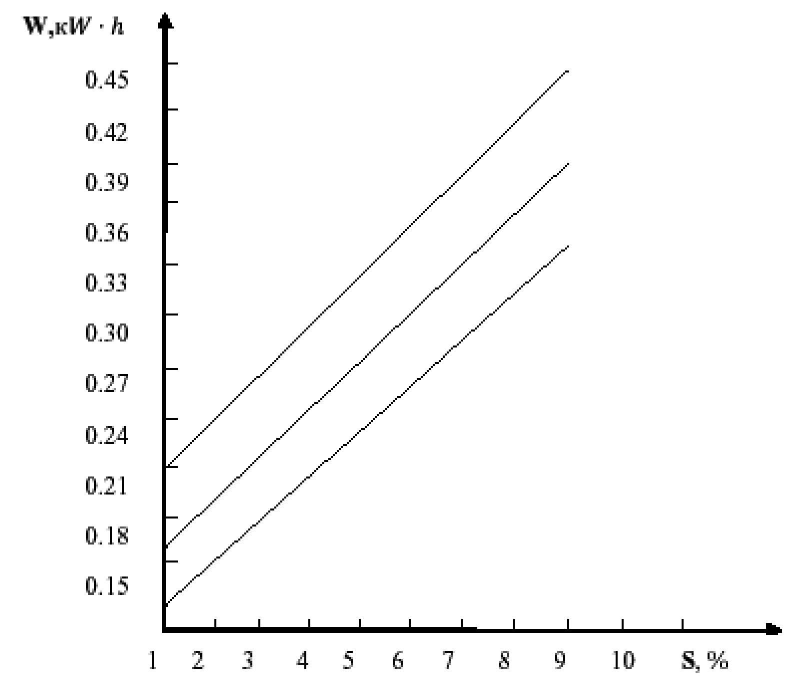
Therefore, it takes 0.266 to 0.415 watts of electrical energy to heat 1 kg of rubber per 1 K. Thus, to heat 1 kg of rubber to 500 ^{0}C (note that depolymerization process does not require more than this), a minimum of 0.133 to 0.208 kW·h of electrical energy would have to be spent.

The process of mechanothermal destruction has another significant difference from conventional rubber pyrolysis. With a gradual increase in temperature due to mechanical stress, those bonds in the polymer that have the least strength are the first to break.

Table 4. Dissosiation energies

Type of bond	Dissociation energy, kJ / mol
Hydrogen-hydrogen	432
Carbon-carbon (single)	345,6
Carbon-carbon (dual)	602 ± 21
Carbon-sulfur (single)	272
Methyl-carbon ($–CH_3 \rightarrow –CH_2– + H$)	142 ± 4
Methylene-carbon ($–CH_2– \rightarrow –CH= + H$)	≈ 382

The figure (drawing2) shows the boundary values of the increase in the values of electric energy for the pyrolysis of rubber, depending on the sulfur content. From the figure it follows that at high sulfur contents (from 5-6% and higher), the energy consumption can double, and even triple at a sulfur content of more than 10%. Since automotive rubber can contain up to 18-20% sulfur (in truck tires), and for heavy vehicles the mass fraction of sulfur can reach 28-30%, a sharp increase in power consumption should be taken into account when pyrolyzing such rubber.



Drawing 2. Dependence of the average power of rubber pyrolysis on the sulfur content.

- Thus, based on the target of research (worn-out automobile tires) that contain, in addition to rubber, from 3 to 5% sulfur and about 15-20% of carbon black, and also, taking into account heat transfer by pyrolysis products, we can calculate average power consumption of electric energy required for mechanothermal processing of this typr of rubber goods.

The average value of the heat capacity of rubbers of the indicated content with a volcanizing agent (sulfur) and carbon black is:

$$\overline{C_p} = 1226 \left[\frac{W \cdot s}{\text{к}g \cdot \text{К}}\right]$$

which corresponds to 0.31 ± 0.04 kW·h of electrical energy consumption per 1 kg of rubber if heated to 450 K.

As a comparison, with the usual pyrolysis method, the energy consumption is about 1.75 kcal for heating 1 kg of rubber per 1 K [8]. If converted to electric power units (when heated to 450 K), it is about 0.9 kWh per 1 kg of rubber.

Conclusion.

The calculations evidenced the undoubted promise of the new method of processing worn rubber products. The obtained values of power consumption are 3 times less than in the conventional rubber pyrolysis, which confirms the effectiveness of this new method of solving the global environmental problem of our time.