

# Investigation of the Influence of Acoustic Oscillation Parameters on the Mechanism of Waste Rubber Products Combustion

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**Abstract.** The article presents an analysis of the used methods of recycling of waste rubber products. The worn out tires are exposed to natural decomposition only after 50 - 100 years, and toxic organic compounds used in the manufacture constitute a danger to the environment. It contemplates a method of recycling waste rubber products in devices where pulsating combustion is realized. The dependence of the influence of acoustic pulsation parameters on the combustion mechanism of waste rubber products and on the composition of combustion products was experimentally investigated and established. For this purpose, the setup scheme based on the Rijke effect is optimized. The resonance pipe is coaxially embedded in the shaft. The known mathematical model of finding the combustion zones in the Rijke pipe, corresponding to the gas flow oscillations with the maximum amplitude, is applied to the chosen scheme. Investigations were carried out for three positions of the grate relative to the lower section of the experimental pipe, in which 1st, 2nd, 3rd modes of oscillation are formed. There are favorable conditions arise for the secondary combustion of mechanical particles entrained in the gas flow in the tube. The favorable conditions for afterburning also include the fact that through the upper section of the resonant pipe, the ambient air, caused by the features of the standing wave, is mixed into the gas stream. A comparative analysis of the change of gas concentration composition along the length of the resonance tube is carried out. It is established that the basic mode of oscillations contributes to the reduction of nitrogen oxides, in comparison with the oscillations occurring simultaneously at several harmonics, considering the main one. The results of research for the three positions of the grate in relation to the lower section of the installation are presented in tabular form, in which 1, 2, 3 modes of oscillation are formed. The analysis of experimental results confirms that the content of harmful compounds in the gas emissions below the maximum allowable norms.

## 1. Introduction

Nowadays the problem of disposing the large quantities accumulated industrial and household waste is acquired special urgency. Therefore, the question about using of secondary resources with maximum efficiency arises more and more acutely. Using out-of exploitation used tires and waste rubber as an alternative fuel is very perspective. Burning tires is approaching commercial fuels like black oil by quantity of generated heat [1].

Out-of exploitation used tires are stockpiled publicly or thrown in a landfill or buried in the ground. So they are exposed to natural decomposition only after hundreds of years, and organic compounds with toxic properties which used by manufacture are of great environmental hazard. Therefore, used recycling technology, including recovery of rubber products, should be ecologically clean and economically advantageous.



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Thus, the reduction or even exclusion of harmful emissions into the atmosphere is an important issue in the field of environmental protection and ecology in general.

Various methods of recycling waste rubber products are used currently. In particular, the crumb rubber used in road construction in order to reduce the noise of automobile vehicle wheels. It is possible to obtain powders, short fibers, different dispersion degree crumbs of them, and use them as additives (or bases) in the manufacture of new products [2, 3].

However, current physical methods of tire recycling into rubber crumb are characterized by complicated processing technology and high energy costs. For example, the process of mechanical grinding of tires, especially with metal cord, require high energy expenditure, and pressure-destruction tire recycling technology, despite its apparent simplicity, is very complicated.

The drawbacks of low temperature processing used tires are the complexity of delivery, storage and the high cost of liquid nitrogen, complexity and high energy production in general.

Chemical methods for recycling used automobile tires, in particular at high temperatures, consist in thermal decomposition (destruction) of polymers in a given environment and receive processing products for various purposes. Liquid and gaseous pyrolysis products can be used not only as a fuel. They can be used as softeners for rubbers regeneration. Pitch pyrolysis resin is a good softener which can be used itself or in admixture with other components. The heavy fraction pyrolysate as an additive to bitumen is used in road building and can enhance its elasticity, resistance to cold and moisture. However, the recycling of used tires at high temperatures is very complex and energy-intensive process as mentioned above [4, 5].

## **2. Materials and Methods**

Using unstable, namely pulsating (vibrating) combustion mode - one of the most promising ways to solve the problem of recycling waste rubber products. The acoustic oscillations arising in continuous media can intensify a series of processes in thermal systems. It is known that heat and mass transfer processes (mixtures formation, evaporation, heat transfer from the gas to the walls, heat exchange stream by reacting with heated bodies and others) are significantly accelerated and particle agglomeration and coagulation of the aerosol improves in the vibrating flow. Moreover, the calorific intensity of furnace volume is increased and completeness of fuel combustion compared to evenly combustion mode is improved by pulsating combustion. Vibrations cause additional air entering to the combustion chamber in the installations with mechanical or aerodynamic valve. These advantages can be used in power installations with moderate forcing combustion process in which the amplitude of acoustic oscillations will not be so large to cause any serious consequences. The prospects for the application of pulsating combustion for the combustion of solid, liquid and gaseous fuels (including alternative) are obvious.

A number of authors found [2, 5, 6] that the pulsating combustion is achieved by high combustion efficiency. It is achieved at rather low excess of air. As is known, the rate of combustion of condensed fuel, solid or liquid, is limited by the rate of oxygen mass transfer processes to the burning surface and the outflow of combustion products from it. This object is successfully solved in a pulsate system where fuels heavier particles cannot follow of fluctuations of the medium, whereby the area around the particles released from the combustion products and oxygen falls therein periodically.

In modern power installations intensification of the combustion process is carried out by using special blower-draft devices, by selection of optimum constructive scheme, by the influence of different frequencies fluctuations to the combustion zone and others. However, these methods complicate the construction of furnaces. And desired effect is not always achieved. Therefore, the most important direction in solving this problem is the development and creation of heat power installations, in which simplicity and reliability of the construction would be combined with a high calorific intensity of the combustion chamber, combustion efficiency, low concentration of carcinogenic substances in the waste gases [7, 8].

The most promising are the heat power installations (flue device), which is being implemented pulsating combustion [9].

**Objective:** to experimentally investigate and establish the dependence of the effect of the acoustic pulsations parameters on combustion mechanism of waste rubber products and the composition of the combustion products.

1. For this purpose, installation scheme based on Rijke effect have been optimized. The resonance tube is mounted coaxially to the shaft. The ratio of cross-section areas of the resonance tube and shaft corresponded to 1:1, 36.

2. The known mathematical model for finding the combustion zone in a Rijke tube corresponding to oscillations of the gas stream with the maximum amplitude was applied to the chosen scheme. The formula for determining the location of the grate in the tube with maximum amplitude of oscillations will take the form [10]:

$$\frac{x}{L} = \frac{1 + 4m}{4n}, \quad (1)$$

where

$m = 0, 1, 2, 3, \dots$

$n$  - harmonic number

$L$  - tube length

$x$  – grates position relative to the lower slice installation.

3. The composition of the waste gas was determined by gas analyzer DAG-16.

Below are shown in tabular form the results of studies for three grate positions relative to the lower slice of installation in which are formed 1, 2, 3 oscillation modes. When  $X = L / 4$  acoustic waves generated modes 1, with  $X = L / 8 - 1$  and 2 modes simultaneously, with  $X = L / 12 - 1, 2, 3$  modes simultaneously.

**Table 1.** Average concentrations of carcinogenic substances in the waste gases at  $X = L / 4$ .

measuring points	$\alpha$	CO <sub>2</sub> %	CO ppm	NO ppm	NO <sub>2</sub> ppm	NO <sub>x</sub> ppm
1	1.2	2.6	1359	169	7	176
2	1.4	2.8	1133	146	22	168
3	1.5	2.4	965	112	3	115

**Table 2.** Average concentrations of carcinogenic substances in the waste gases at  $X = L / 8$ .

measuring points	$\alpha$	CO <sub>2</sub> %	CO ppm	NO ppm	NO <sub>2</sub> ppm	NO <sub>x</sub> ppm
1	1.2	2.8	1251	197	22	176
2	1.4	2.5	1109	163	21	179
3	1.5	2.2	829	121	6	141

**Table 3.** Average concentrations of carcinogenic substances in the waste gases at  $X = L / 12$ .

measuring points	$\alpha$	CO <sub>2</sub> %	CO ppm	NO ppm	NO <sub>2</sub> ppm	NO <sub>x</sub> ppm
1	1.2	3.8	1212	257	22	179
2	1.3	2.6	1082	181	21	202
3	1.6	2.0	741	151	6	151

### 3. Results

It should be noted, the zone of pressure pulsation with maximum amplitude is located in the middle part of the oscillation circuit than the location of the grate at a distance  $\frac{1}{4}$  of the contour length from of the lower slice. This pressure epure is typical for the pressure epure of a standing wave in the tube opened on both sides when oscillations in it excited with the only difference being that the pressure

antinode in the present case a few displaced from the center of the oscillating circuit. It is explained by the speed of convective flow in the resonant circuit. It should be noted that the position of the grate according to the  $\frac{1}{4}$  length of the oscillating circuit from its lower end, promotes the formation of the acoustic oscillations with maximum amplitude in the contour.

As shown in the tables 1,2,3 concentration of carbon dioxide  $\text{CO}_2$  in the gas stream compared with concentrations of carbon monoxide CO and nitrogen oxide NO as it approaches the outlet tube slice is slightly reduced. This indicates that there are favorable conditions in the tube for afterburning of mechanical particles entrained in the gas stream. The fact, that throw the upper slice of the resonance tube ambient air caused by the features of standing wave mixes into the gas flow, is a favorable condition of afterburn to. Undoubtedly, the above factor enriched waste gas with oxygen, contributing to a more active afterburn of mechanical particles. The air ratio in the flow increases, and the concentration of carbon monoxide CO and nitrogen oxide NO reduces with increasing distance from the zone of combustion. At the same time it should be noted, only a slight change in the concentration of carbon dioxide  $\text{CO}_2$ , when would be expected a significant reduction in its concentration along the length of the resonance tube by analogy with other gases.

#### 4. Contribution/Originality

From comparison analysis of the gas composition concentration changes along the length of the resonance tube also follows that the main oscillation mode contributes to lower nitrogen oxides (compared with vibrations occurring simultaneously at several harmonics, considering basic). Thus, the flow oscillations with a frequency  $f = 84$  Hz nitrogen oxide concentration is 169 ppm, for flow fluctuations which occur simultaneously with the main higher harmonics, the concentration of nitrogen oxides is 257 ppm [11, 12, 14].

#### 5. Conclusion

Analysis of the results of experimental studies confirmed that in applications where pulsating combustion is implemented, the content of harmful compounds in gas emissions greatly reduced. The prospects for the application of pulsating combustion for the combustion of solid, liquid and gaseous fuels (including alternative) are obvious.

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