ANALYSIS OF MODERNIZATION OF TIRE RECYCLING MACHINE FOR IMPROVEMENT OF ENVIRONMENTAL SUSTAINABILITY AND FEASIBILITY

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ABSTRACT

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The main idea of this thesis is twofold: first of all to develop utilization processes for used tires and, second, to study and explain the serious ecological problems in the tire recycling and waste utilization sector in Russia. This thesis was commissioned by a recycling firm called Istra Ecologia Company. The thesis presents improvements in a tire recycling machine owned by this company. The owner of the plant has developed a modernized version of the system, and seems to have solved some difficult challenges that exist in the current plant. The work for this thesis involved making an in-depth analysis of the feasibility of the new plant with an eye on financial and ecological performance, as well as on investment and profitability questions. Nevertheless, due to outdated technical solutions, the equipment and the used processes certainly have some technological challenges still to be solved in order to optimize the whole process, taking into account not only the end products but also keeping an eye on sustainable development.

In this work, the specific features and the operation of the old plant are discussed in detail. Furthermore, a full analysis of the pyrolysis process is presented, including the properties of the products, as well as the technical and financial figures. The work describes the main components and layout of the old plant utilized for processing used tires and rubber products. Also, the working process itself is described, including information about the environmental impact of the plant. Quantitative and qualitative methods have been used in this research.

In this thesis, the main problems with tire recycling in Russia have been explained to the reader. A comparative analysis of different methods of tire recycling has been conducted in order to enable the reader to understand the pros and cons of each method separately. The characteristics of the old recycling machine have been explained in detail and the modifications have been presented. The results shows that emissions have been minimized and productivity has increased. It should also be noted that improvement in the quality of pyrolysis products has also been achieved.

Key words: Tire recycling, pyrolysis, waste, rubber products, ecological sustainability, feasibility.

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ABBREVIATIONS AND TERMS

Tamk - Tampere University of Applied Sciences

m - meter

kg - kilograms

M_i - total emissions of the pollutant

G_i - maximum one-time emission of pollutant

t - time of work selected (pollutant in the day, hour)

N_i - the number of working days of the source selection

K_i - concentration of pollutant

Q - consumption of gas-air mixture m/s,

P_1 - plant capacity in tons/shift

K - the load factor

V - the volume of raw materials of the furnace-reactor(meter cube)

P - the proportion of raw materials, t/meter cube

P_2 - capacity of the unit to release the finished product

F - yield coefficient

Economical data

Z_c - operating costs

Z_1 - salary(annual payroll for workers)

Z_2 - social contributions

Z_3 - material expenditures

Z_4 - amortization expenses

Z_5 - other expenses

n - number of employees that service equipment

C_1 - an average hourly rate of maintenance of equipment

T - annual fund operating time

K_1 - coefficient of premiums and co-payments

K_2 - coefficient taking into account the additional wages

R - installed capacity of energy consumption (kWh)

T - the annual number of hours of use of power load (hour)

K_3 -coefficient of demand

K_4 - coefficient of equipment load

K_5 - coefficient of electricity shutdown

C - cost of 1 kWh power of electricity

1 INTRODUCTION

Environmentally compliant recycling of used tires and rubber products is one of the biggest global ecological challenges today. In Russia, typically, disposal of waste tires nowadays is simply carried out by “dumping” them to the nearest "convenient" location or by disposing of in a landfill. Used tires are, more of less legally mixed with other waste in landfills. The number of tires stored in the world in landfills is estimated at one billion pieces. (Chibisov, A., 2012. 5.)Disposed of tires at landfills and dumps or scattered in the surrounding areas brings about a serious long time pollution impact. Lack of alternatives for tire recycling increases the number of tires stored in landfills. Certainly, this method cannot be called environmentally sustainable because tires degrade over a hundred years.

The amount of recycled tires in Russia is about 20% of the total. Considering, that the amount of used tires constantly increased, it causes an irreparable damage to the surrounding nature. For comparison, the level of recycling of used tires in Europe is 76% in the USA - 87%, Japan - 89%. (Chibisov, A., 2012. 33.) Used tires, according to the legislation of the Russian Federation are waste of Class IV and subject to mandatory recycling. Unfortunately in Russia, used tires are either just left by the roads (in case of puncture or damage) or buried. Used tires, left in the nature, form a serious hazard: they are not biodegradable, they are flammable and form a perfect breeding ground for rodents and insects, turning them into an "incubator" for different infections. Thus the problem of tire recycling reaches serious global dimensions.

At the same time human needs in natural resources are steadily increasing and value of them is constantly increasing, too. One of the ways to reduce the consumption of natural resources is the use of material resources accumulated in the waste. Rubber waste and used tires are valuable secondary raw material resources.

Modern industry should be focused not only on the consumption and production, but also to preserve the environment. Recycling is currently the most effective way to improve the sustainability of the environment. The purpose of this work is to analyze and identify what is the best method of recycling rubber and improving environmental efficiency of the recycling of tires.

2 THE PROBLEM OF DISPOSING TIRES

2.1 Basic problems of disposing tires

The ever-increasing flow of cars, leads to a colossal accumulation of used tires. Unfortunately, in Russia tire recycling industry is not very interested to invest due to the high investment cost and low economical effect or profitability. Developed industrialized countries have legislation, which imposes and stimulates the use of recycling. Recycling of rubber products has a whole range of financing possibilities. According to my studies of Chibisov`s work, the European Union has formulated a long term environmental sustainability strategy involving:

- Prevention of pollution;
- Recycling and reuse of waste materials;
- Optimizing the final treatment of waste;
- Regulations on transportation of waste;
- Measures to rehabilitate the environment;
- Increase the knowledge of people and guidance in sustainable consumption;
- Integration of environmental parameters in the product standards (Chibisov, A., 2009. 14.)

According to my research the main initiator of the solution in Russia is also the state. Government funding, with all its limitations and difficulties, does not contribute to the highly profitable projects. It is necessary to create a comprehensive public program for the collection, temporary storage, processing and market development. The existing legislation of the Russian Federation in the field of waste management has a number of challenges:

- There is no obligation of the manufacturer (importer) for the disposal of their products at the end of the life cycle.
- In the legislation of the Russian Federation there are no real economic incentives to enhance the commercial use of waste as secondary material resource.
- There is no established authority for regulation of waste management between state and municipal authorities.
- There is no legal regulation for the management of waste collection and logistics on the regional level.

Factors hindering the development of the manufacturing in sector of recycling rubber products are:

- No public authority, responsible for the organization, control and management of collection and use of waste and secondary resources.
- No utilization policy of waste rubber products, which does not allow raw materials existing in Russia to be effectively refined: volume in excess of 150,000 tons per year.
- The lack of dedicated independent laboratories for quality assessment of road materials from waste rubber.
- Road construction facilities or companies are not ready to widely use crumb rubber in the process of road construction, due to the lack of special equipment and technical limitations of the existing technology.
- Lack of effective system for cooperation with international partners - manufacturers and importers of tires and rubber waste processing companies

The annual growth of used tires in Russia is estimated at about 50 million pieces. According to the studies of the Institute of Tire Industry, only in Moscow every year, up to 60 000 tons of tires with a metal or a fabric cord fall out of service. In Russia, the overwhelming majority of used tires is not repaired or sent to recycling facilities. There are no facilities for permanent warehousing, temporary warehousing, and either placement of this waste. Therefore used tires are “thrown” mainly on the terrain, roadside in the suburbs and adjacent road areas.

The inspectors from Istra Ecologia and I took samples from the Moscow area landfills, where tires are disposed by burning. Examination showed that the soil in the vicinity of the landfill to a depth of two feet is soaked in heavy metals. Sample results obtained show that the concentration of cadmium in that particular soil exceeded several times the allowed limits – and cadmium is one of the most dangerous elements for human being. Person consumes for example potatoes or other products, grown in the mentioned soil, he/she can die in six months. (Chibisov, A., 2012. 4.)

Tires pollute the environment due to high resistance to external factors (sunlight, oxygen, ozone and microbiological effects). In addition, tires involve a high risk of fire and can the products of burning have extremely harmful effects on the environment (soil, water, air). The fact that most of the used tires in Russia are dispose to the landfill leads to the following main negative consequences:

- Unfavorable ecological situation in the zones of landfills.
- Release of toxic substances in the fire.

- The inefficient use of resources.
- Violation of international environmental agreements.

Rubber tires are valuable polymeric material: one ton of tires contain about 700 kg of rubber, which can be reused for the production of fuel, rubber products and materials for construction purposes. At the same time, recycled rubber can be used for playground equipment (Picture 1), marine applications, the stadiums, for power lines and in a number of other industries.

Picture 1. Example of use of used tires in playground equipment (Source http://www.business-equipment.ru/pererabotka/pererabotka-shin-v-domashnih-usloviyah.html)

Worldwide experience shows that an effective system of collection and utilization of tires can exist only when proper economic incentives and legislative regulations exist to allow profitable operation for all the involved participants. In Russia, these goals can be best solved only by imposing certain liabilities for tire manufacturers and suppliers. Also, not less importantly, the car park in Russia and therefore the number of waste tires is subject to substantial growth. Therefore, both in the near and in the medium term future, this problem will not disappear by itself, but instead it gets more severe.

2.2 Prospects of using waste rubber products

In July 2006, the European Union banned the law which allowed burning and burying of used tires in the ground. (Chibisov, A., 2012. 13.) Also, many other countries have begun an active search for alternative ways of recycling. For example, the University of Wisconsin (USA) has developed a new way of processing used tires; the tires are filled and frozen with liquid nitrogen and consequently get brittle as tempered glass in that process. By means of this process they produce crushed tires and raw materials to be used in the construction of road surface. Tests have shown a great improvement of friction coefficient of the road with car wheels and the lowest noise level (Chibisov, A., 2011, 19.)

Cost of raw materials for road construction made of tires does not exceed the cost of asphalt. American Bill of Transport supported the application of rubberized asphalt, for which up to 30% of used tires accumulated annually in the U.S. will be used. (Chibisov, A., 2012. 23.)

Another way to use of tires has Bulgarian experts (rubber plant in city Pisaridzhik). For several years they have produced rubber tires for rail tracks in the mines. Such tires have several advantages: three times lower price than traditional tires (concrete), better absorbtion of shocks and muffling of noise, resistance to mine water, does not need the ballast of gravel, and at the end of the life cycle, these tires can be re-processed.

Russia does not have well developed system for recycling of used tires and rubber waste. Situation is shown in (table 1).

Table 1. Use of tires and rubber waste in different countries

Country	Formation volume, Kt	Land-filled,%	The generation of energy,%	Retreading,%	Getting rubber crumb,%	Exports%	Others %
Germany	550	2	38	18	15	18	9
UK	450	67	9	18	6	-	-
France	425	52	10	13	6	19	-
USA	2800	59	22	9	9	3	1
Japan	840	8	43	9	12	25	3
Russia	800	96	-	1	3		

(Source: Chibisov, A., 2011. 19.)

There are only 40 companies involved in tire and rubber waste recycling in Russia. Obviously, equipment for recycling of tires is relatively expensive, but the profitability is correspondingly high: the payback period is only one to three years. Used car tires contain valuable raw materials: rubber, metal, textile cord and other processed products. Calorific value of 1 ton of waste tires is equivalent to the heat of combustion of 1 ton of high-quality coal and 0,7 tons of fuel oil, i.e., used tires have high thermal capacity to be used as fuel, as it consist mainly of petroleum products. A comparison of the energy content of tires, fossil fuels and other fuels is given in Table 2.

Table 2. A comparison of the energy content of tires, fossil fuels and other fuels

Type of fuel	Fuel grade	Calorific value, kcal / kg
Natural Gas	Fossil Fuels	556
Fuel from used tires	Fuel from used tires	8611
Coal	Sub-bituminous coal	5833
	Bituminous coal	7056
Wood	Raw wood, including flake (wood) waste	2431

(Source: Chibisov, A., 2012. 23.)

The recycling of used tires and rubber products is one of the greatest ecological and economic challenges for all developing countries. Nonrenewable and expensive natural crude oil requires implication of secondary resources as efficiently as possible, i.e. instead of building up mountains of waste we could create a new source of cheaper energy for the industry - commercial recycling.

Expected results from the introduction of tire recycling in Russia:

- Addressing the environmental situation.
- Processing mechanically up to 70% of tire waste.
- Creation of additional conditions for the development of the industry to obtain the final product for rubber processing in Russia (rubber cover, shoes, kerosene, etc.).
- Creation of jobs and new business.

3 METHODS FOR RECYCLING USED TIRES

3.1 Classification of methods

The problem of recycling waste rubber arose from the need to dispose of tires and other rubber products that are not suitable for recovery. Disposal of waste by dumping in industrial waste dumps, storage on the ground or under water, does not solve the problem of disposal. Resistance of rubber to mechanical, biological and chemical exposure makes it possible to recycle rubber products. After recycling tires and rubber materials undergo only minor structural changes. This alone allows us to reuse obsolete rubber products such as whole or cut into pieces tires in the construction of roads, protective structures, fences, artificial reefs.

Along with the requirement of minimize negative impact on the environment by recycling methods, we also need to maximize recovery of raw materials and minimize negative impact on existing production. Site products of waste should have a market, and the cost should be low enough.

In accordance with the classification methods waste management can be divided into groups (Figure 1), which differ in the nature of changes in the structure of rubber and other polymeric components: physical, physicochemical and chemical.

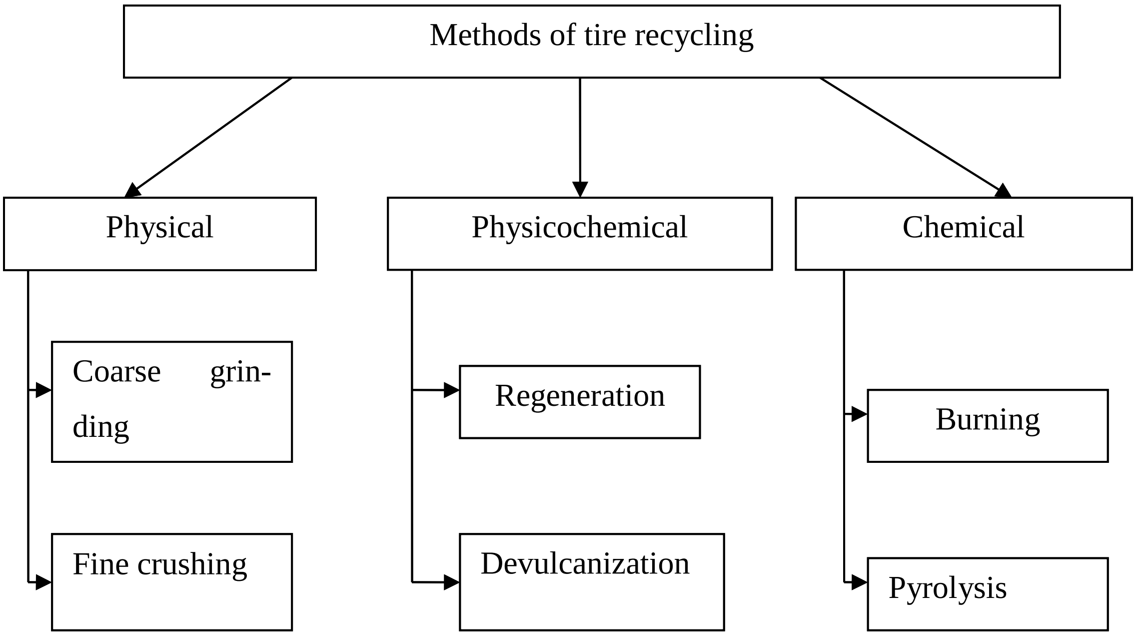


Figure 1. Classification of methods for recycling waste rubber (Production schedules of industrial plant for recycling of used tires with method of pyrolysis, 2006. 6.)

Physical method of processing

Refinement (or splitting) - is the process of separating solids into pieces. Grinding efficiency is determined by the degree of grinding. The main task of the theory of grinding is to establish the relationship between particle size of crushed material, the physico-chemical, mechanical properties, the cost of energy for crushing and grinding equipment parameters. It was proposed, that the energy consumed for crushing, was to be considered directly proportional to the newly formed surface (Rittinger's law), to volume or mass of ground rubber material (theory of Kirpicheva-Kick) and to their mean geometric volume and surface (Bond Theory). (Galimov, E., 2010. 69.) Later Houlteyn on basis of experiments concluded that the milling energy is used not only for the formation of new area of surfaces (reducing the volume and weight), but also for the deformation of the material without damaging it and the friction caused by the material rubbing against the working surface of grinder. (Chibisov, A., 2011. 19.)

According to P.A. Rehbinder, the energy expended in the shredded material is the amount of work directed to the deformation of the body and the formation of new surfaces. It supposes that the material should be destroyed with the maximum voltage. (Galimov, E., 2010. 69.) Compared with other theories, P.A. Rehbinder`s theory is more progressive as it allows separating and assessing the individual factors of the energy consumption, evaluate the effectiveness of the grinding process and predict the main possibilities of its optimization. Anyhow, this theory has its flaws, because it does not take into account the generation of thermal, electrical, chemical energy, which from their part consume also power of the outer sources.

The grinding process, despite its apparent simplicity is very difficult. It is not only about determining the nature, magnitude and direction of loads, but also involves the difficulties in quantifying the results of destruction.

Physicochemical treatment methods

Regeneration - one of the oldest, but still widely used industrial method of processing waste tires and other waste. This process consists of breaking the spatial grid of vulcanized rubber by thermal, mechanical and chemical means. The result is plastic product that can be processed again and partly replace the rubber.

Composition of regenerated materials differs from composition of the original material. During the process of regeneration excipients are added to rubber. They are emollients and activators of regeneration. In this regard, the technical effect of the use of reclaimed material is limited: they only improve the workability of rubber compounds.

Company «Gould» (USA) has developed apparently similar to a method of treating rubber crumb mixed with emulsifiers and caustic alkali-first on the rollers, and then in the disk mill with distilled water and drying in a vacuum. The product containing, according to the company not less than 90% of particles less than 20 microns. (Chibisov, A., 2012. 27.)

Devulcanization of rubber

One very interesting challenge in processing of secondary rubbers is the restoration of their plastic properties by means of selective exposure of the intermolecular cross-links to different agents. As a result their spatial grid is broken and we can obtain even linear rubber molecules.

The way of devulcanization is based on dielectric heating crumb size of 6-10 mm by microwave energy. Thus obtained powder (at a content of up to 20%) practically does not affect the properties of the rubber. (Galimov, E., 2010. 87.)

Chemical methods of processing

The second group includes methods that lead to irreversible changes in the deep structures of polymers. Generally, these methods are carried out at high temperatures and lead in thermal decomposition (degradation) of polymers in a particular environment.

Incineration

The high heating value of rubber 16,000 Btu/lb (8600 kcal / kg) is used to generate heat energy. There are a lot of industrial incinerators of used tires, working in the U.S., UK, Switzerland and Germany.

Typically the burning process involves burning of used tires and other rubber waste without pre-processing (grinding) and sorting. That kind of process gives the possibility to complete extraction of the metal components, but generally it has a negative impact on environment. In spite of some economic feasibility of burning rubber waste to produce heat energy, it also has some main drawbacks, one of which is the fact, that instead of burning, the rubber waste could be processed further to products to be used as raw materials of higher added value for the rubber industry.

Pyrolysis

It is a form of treatment that chemically decomposes organic materials by heat in the absence of oxygen. Pyrolysis typically occurs under pressure and at operating temperatures above 430 ℃ (800 °F).

This is the most widely used thermal processing method. The end products of pyrolysis of waste rubber products are various gaseous, liquid and solid products. Its efficiency ratio and product multiplicity depend on the conditions of the process. According to the known practical data, 1 ton of waste rubber after pyrolysis can turn into 10.2 cube meters of pyrolysis gas or 450-600 liters of pyrolysis oil or 250-320 kg of pyrolysis char. Interest in pyrolysis is due to the fact that it can be used for utilization of a significant number of rubber waste categories, and the products can be used in various industries as raw material for the production of asphalt, wax, anti-corrosion coatings and fuel.

Increased interest in pyrolysis research has helped promote the possibility of carbon black used as filler rubber.

3.2 Comparative analysis of various methods

I have done comparative analysis of various methods, found pose and ponds of each method. Rubber products are source of long-term environmental pollution due to the high resistance to the natural factors. It is extremely difficult to extinguish a fire in a landfill in a case of burning tires. In case of an underground fire it is almost impossible to stop the fire and it can ultimately turn into a regional ecological disaster. Tire dumps are breeding grounds for many disease carriers that cause epidemics in the surrounding areas. The question of recycling waste rubber products has two aspects:

- The environmental sustainability.
- The task of maximizing the use of valuable raw materials.

Recycling of secondary raw materials is an important resource-saving trend in the conditions of increasing reduction of natural resources. Waste rubber products, including used tires, form a significant source of raw materials. Used tires are equivalent to 90% of the total of this kind of secondary rubber raw materials. Thus, the development of methods of treatment and disposal of waste rubber products is extremely important.

Analysis of physical methods

The economic feasibility of recycling used tires is very high. Tires after recycling do not loss it properties and can be used to produce new materials for construction and industrial applications. Thus, recycling of waste rubber products does not only reduce pollution, but also allows returning raw materials to the production.

Advantages of crumb rubber:

- effectively used in tire industry
- the manufacture of other rubber products
- successfully replacing expensive primary materials in road construction
- the manufacture of various structural, thermal insulation and anti-corrosion materials.

Disadvantages recycling tires into rubber crumb:

- Grinding process. Despite its apparent simplicity, it is a very difficult process, not only to determine the nature, magnitude and direction of loads, but also to define the difficulties of quantifying the results of destruction.
- Significant multiple strains abrade elastic material, increasing its temperature and increase the shear resistance results in increased power consumption and intensive wear and tear, as well as to the low yield of marketable products.
- With decreasing size of crumb rubber derived energy increase approximately in proportion to the total area of its surface. It is known, for example, that the chafing rubber on the rolls to the size of about 0.5 mm crumb spend energy for more than $1 kWh/kg$
- It is not effective to recycle rubber products, reinforced with metal. The use of such equipment in the processing, such as tires with metal results in a substantial increase in energy consumption, intensive wear of equipment and high costs for the replacement of wear of cutting tools.

The use of cryogenic techniques can reduce energy consumption for grinding and separate reinforcing elements of products for the mechanical processing of rubber. The main disadvantages of cryogenic processing methods are:

- High energy costs associated with the need to obtain a sufficient amount of liquid gas, and achieve and maintain a low temperature in the chamber. It is known that the total costs of processing such as more than $1 kWh/kg$.
- In addition, an entire grinding process of rubber at low temperatures requires a unique technique, able to work under these conditions, considering also the entire complex insulation.
- With large rubber sizes low thermal conductivity leads to considerable process time. The cooling process as a whole and super cooling of the outer layers of material causes even greater increase in the total energy consumption while reducing the performance of the equipment. Therefore, when using this method, prior crushing is also extremely useful.

The use of crumb rubber in critical rubber products, such as protector of tires, requires certain technical and quality characteristics. It includes restrictions on the content of the material cord fiber and metal. This requires the separation of rubber and metal and textile fragments reinforcing frame.

Analysis of physicochemical methods

One widely used commercial method of processing waste rubber tire is regeneration. It is a process of manufacturing plastic products by devulcanization, crushing process and extraction of the reinforcing elements of rubber products. (Ivanov, R., 1985., 57.) Vulcanization, a chemical process for converting rubber or related polymers into more durable materials via the addition of sulfur or other equivalent "curatives" or "accelerators" at the same time devulcanization is the process by which the polymer attributes of vulcanization are reversed.

The process of regeneration is accompanied by a significant amount of harmful emissions. Reclaimed rubber compound consists of a gel fraction, which preserves the sparse network structure of the vulcanization, and sol fraction containing relatively short segments of branched chains with a molecular weight of about 10,000. Since the network structure is maintained in regenerate vulcanization, the introduction of reclaimed rubber in the mixture occurs microinhomogeneitly, which affects the strength properties of rubber. The presence of low molecular weight fractions in the regenerate reduces wear of rubber. In this regard, the regenerate is almost never used in the tread rubber.

(Ivanov, R., 1985. 59.) Currently the use of reclaimed rubber industry is limited mainly to use it as a processing aid, that improves the workability of rubber compounds, and as a raw material for non-critical items.

Production and consumption of reclaimed rubber almost in all countries are gradually decreasing due to increased requirements for quality rubber and the expansion of production of new types of cheap synthetic rubber. The powder produced by the method of devulcanization, suggest getting by briefly heating the surface of an open flame, high-frequency radiation, which in turn is unsafe for staff.

Analysis of method of retreading

Renewal of tires is considered to be the most effective way of recycling waste tires. It is estimated that the price of retreaded tires is 40-55% lower compared with new tires. However, this method is not the solution, because, on the one hand the qualitative characteristics of the recovered tires still leaves something to be desired, and, on the other hand, sooner or later the retreaded tire fails and has to be eliminated one way or another.

Analysis of chemical methods

It can be concluded that the essentially acute problem is the disposal of tires with steel reinforcement and oversized tires.

The simplest method of disposal is incineration of rubber products, widely used at present for used tires. Anyhow, before burning tires usually need to be crashed mechanically and for a more complete and efficient combustion it is better to mix crushed tires with combustible waste. Nonrenewable natural resources make us look for ways to better use of valuable raw materials, than just burning it. Also one of the main disadvantages of waste incineration is the fact that the combustion of used tires, as well as the burning of oil, destroys valuable chemical substances contained in tires.

One of the methods of chemical processing of waste tires and other rubber products is pyrolysis. It is carried out, usually after preliminary destruction and milling products.

Disadvantages of pyrolysis:

- It does not solve the problem of processing large proportion of the total volume of waste products, such as tires, because consumption is limited to the pyrolysis products at much lower levels.
- High energy consumption due to the necessity of heating the processed products to high temperatures, being more than $1kWh/kg$.

The most cost-effective way of recycling is to extract rubber fragments, dispersed materials (rubber crumb) and also the metal and textile reinforcements from the waste rubber products. The implementation of such process and qualitative separation of materials is a complex technical challenge (economically satisfactory solution) which has not yet been found. For this reason, the level of such processes of rubber products is extremely insufficient. We can see the objectives of the pyrolysis process below in Table 3:

Name of Product	Assigning of products
Pyrolysis liquid fuel	Used as a liquid fuel for boilers, heating oil substitute. Applicable distillation into fractions in order to obtain various petroleum products (gasoline, diesel fuel, oil, resin, etc.)
Carbonaceous solid residue (carbon black)	Used as a solid fuel, and can be used for producing of modified liquid fuel, as a sorbent, replacement of activated carbon as a filler in the manufacture of new rubber products.
Pyrolysis gas	Partially used to operate the plant, the rest after burned to heat generators or flares.
Scrap (metal)	It is consists of high-quality steel. It is used for further processing of recycled metal.

Table 3. Purpose of the pyrolysis products (Source: Averko-Antonovich, I.,2010, 22)

Increased interest in pyrolysis research has helped to promote the possibility of getting carbon black which is used as rubber filler. Adding carbon black to asphalt coating increases the coefficient of friction between the vehicle and the road surface, reduces fuel consumption and harmful emissions, improve the environment in the areas of roads. This type of waste is used in the developed countries - especially in the EU and Japan. This is a capital-intensive, but highly effective way to reduce the amount of waste that has no alternative when working with certain types of waste.

The pyrolysis process is economically very beneficial and environmentally friendly, so it is in service in many countries. Process of pyrolysis conforms the European standards and is considered to be an environmentally friendly technology worldwide. This method has been adopted by EU and thus removes all questions about the environmental safety of production.

Recycling tires by pyrolysis has no alternative, as it produces energy and does not pollutes air as much as simple process of burning.

Therefore, comparing the features of different methods, I can recommend the use of pyrolysis as the most efficient method of recycling waste rubber products.

3.3 Practical analysis of mechanical method

Mechanical method involves recycling of tire rubber particles of various dimensions: chips, fragments, pellets. Technological processes and equipment for processing of used tires are made at positive temperatures. Under certain stain rates and the complexity of loading elastomers destroyed with little expenditure of energy. This provided a basis to conduct extensive research to determine the effects of energy destruction of rubber materials in a single action and energy consumption at the grinding process. Nowadays dispersed materials become an important area of utilization of waste. The most complete original structure and properties of rubber waste and other polymers stored by the mechanical grinding. To establish the relationship between size of the material, mechanical characteristics, energy consumption and grinding equipment parameters is extremely necessary for the calculation of shredders conditions and determination of optimal conditions for its exploitation. The grinding process belong to difficult process of mechanical recycling of used tires. It involves determining the nature, magnitude, direction of loads and also difficulty quantifying the results of destruction. Mechanical recycling method is the most widespread in the world because rubber is protected from thermal oxidation, no effect of partial devulcanization (softening and ductile acquisition) and relatively low power consumption. Grinding process runs under normal weather conditions where temperature slightly above ambient temperature. Cooling systems are closed loop which require cooling towers or water flow cooling system. At some stages water comes to the shredding mill as a thin nozzle and assists in cutting process of rubber tires and chips. In mechanical technology is inherent separation of metallic and textile cord for receiving a fine rubber powder by extrusion grinding. Processed products are crumb from 0,2-5,0 millimeters for the production of secondary rubber products. The advantages of this method are low cost and low power consumption.

I visited JSC "Ekoshina" in Moscow by myself and I have done comparative analysis of manufacture, use of rubber crumb, mechanical and cryogenic recycling of tires.

The technology of processing by inherent mechanical grinding of tires to small pieces is followed by mechanical separation of metal and textile cord. It is based on the "fragility" of rubber at high speed collisions, and producing fine rubber powders as small as 0,2 mm by grinding the resulting extruded rubber crumb technology. Line capacity is 5100 t / year. Equipment is successfully used in JSC "Ekoshina" (Moscow).

Description of the production line

The technological process consists of three stages:

- Crushing rubber pieces, separating metal and textile cord
- Preliminary cutting tires into pieces
- Producing fine rubber powder.

Line diagram is shown in Figure 2

1. At the first stage of the process tires come from stock and are fed on tire preprocessing site, where they are washed and cleaned of impurities. After washing, the tire are moved in pre-grinding (units three-stage blade grinder), which is constantly grinding. Dimensions do not exceed $30 \cdot 50mm$.
2. In the second stage pre-shredded tire chips are fed into a hammer mill, where they split up to the size of $10 \cdot 20mm$. The crushing of pieces is processed in a hammer mill and then weight divided into rubber, metal cord, bead wire and textile fiber.

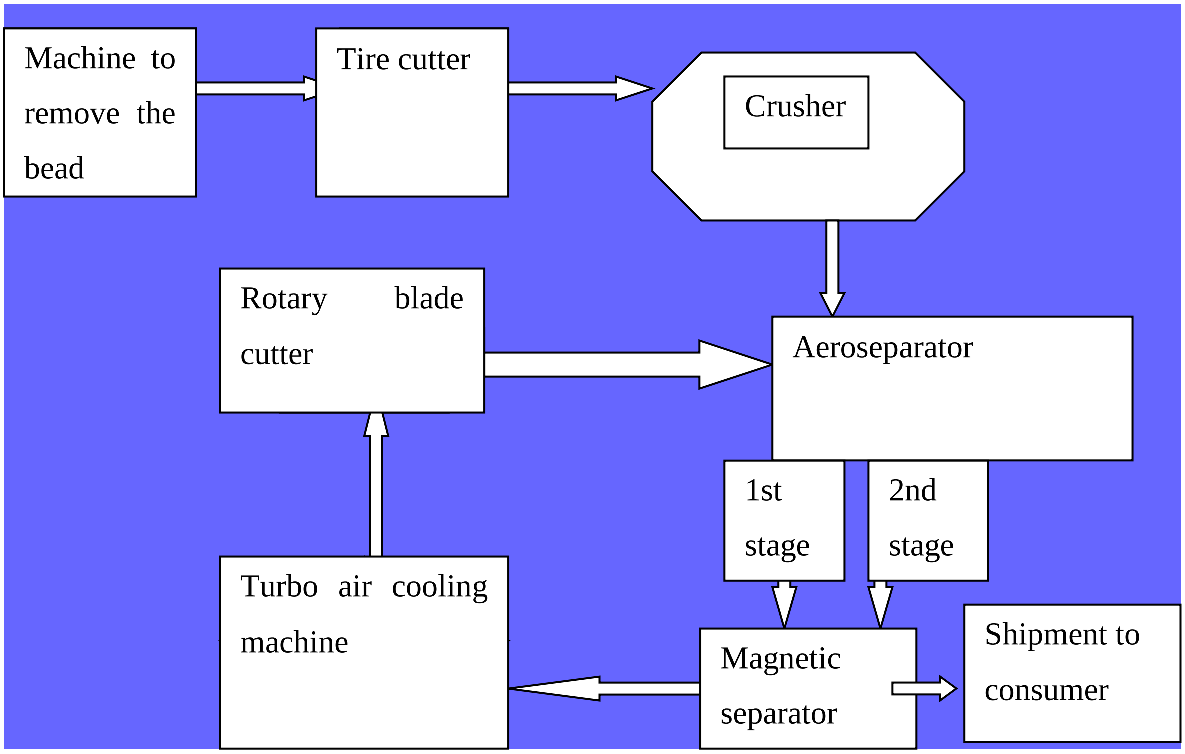


Fig.2. Technological scheme of mechanical processing of tires

Rubber crumb with metal enters the conveyor. From conveyor free metal is removed by magnetic separators and is directed into special bins. Then scrap is briquetted.

At the third phase the rubber is fed into an extruder - chopper. At this stage of processing there are still some textile fiber residues, separating of which is done by with a gravity separator. Cleared of textile rubber powder is fed into the second chamber of extruder-shredder, which carries out fine dispersed final grinding. After that it is unloaded from the extruder into a sieve. Powder has 3 fractions:

1 - fraction – 0,8 ... 1,6 mm

2 - fraction – 0,5 ... 0,8 mm

3 - (optional) fraction – 0,2 ... 0,45 mm (delivery on request).

The advantages of this method are low cost and low power consumption. Disadvantages are obtained of particles that enhance the oxidation process, reduces the crumbs quality, enhances significant wear of cutting and grinding equipment. Production based on formation of harmful gas emissions. More detailed information about manufacture and use of rubber crumb you can find in Appendix 1.

3.4 Practical analises of cryogenic method

Low-temperature (cryogenic) technology is based on the utilization of rubber waste with deep cooling process (from -70 °C to -120 °C). Cryogenic method increases brittleness and cracking of tires. Crushing and separation from metallic cord became much easier. Turbo-refrigerating system is the one of main cooling part in all process of cryogenic recycling. Processed products are crumb rubber and scrap-metal.

Cryogenic grinding has the following advantages compared with refinement at room temperature, i.e., when the rubber is elastic state: lower energy consumption, no risk of fire and explosion, the ability to produce a fine rubber powder with particle size of 0,15 mm, a reduction of environmental pollution.

Efficiency of cryogenic grinding:

- weakening link between steel cord and rubber at low temperature, leading to a partial separation of rubber from the metal
- a sharp decline in the elasticity of rubber and its brittle fracture even at small deformations
- high degree of separation of waste, as well as the use of rubber crumb in the manufacture of new rubber products

- low level of wear and tear (grinding equipment)
- no product caking in mill or on other equipment
- up to 80% improvement of fire safety and working conditions

More detailed information about cryogenic grinding and specification of it process in details you can find in Appendix 2.

3.5 Practical analyses of pyrolysis method

Developer and provider is JSC "ALMAS ENGINEERING" company (Moscow).
I also visited JSC "ALMAS ENGINEERING" company (Moscow) by myself and I have done comparative analysis of chemical method of tire recycling.
The analysis of the elemental composition of tires shows that its basis is carbon and hydrogen, resulting in high temperature combustion. Burning is one of the “wildly” used method of disposal of waste rubber and tires. It is includes pyrolysis and combustion. The elemental composition of tires is shown below in Table 4.

Table 4. The elemental composition of tires,% (Source: Galimov, E., 2010. 52.)

Elements	Protector, %	Carcass, %
C	88,30	70,1
H	7,20	7,7
S	1,64	1,3
Fe	-	18,57
Other	2,86	2,33

Depending on the design the process equipment can utilize crushed and whole tires. The advantages of recycling tires with method of pyrolysis are: environmental friendliness of the process, the ability to produce high quality products. Pyrolysis is executed in a limited supply of oxygen and temperature of 500-1000 ° C. Different types of products are formed during process of pyrolysis and, more importantly, the product may vary depending on the used temperature. The use of significant amount of heat is required only at the initial stage of the pyrolysis process. The average mass balance of the pyrolysis of tires at various temperatures is shown in Table 5.

Table 5. The average mass balance of the pyrolysis of tires at different temperatures (Source: Production schedules of industrial plant for recycling of used tires with method of pyrolysis, 2006. 8.)

Products	°C		
	500	700	800
Solid,%(mass.)	60,5	52,0	44,0
Liquid,% (mass.)	30,3	27,9	17,7
Gaseous,%(mass.)	6,8	18,2	26,2
Losses,%(mass.)	2,4	1,9	2,1
Energy consumption, MJ/kg Products	4,2	5,7	4,6
Temperature of burn-ing(products), MJ/kg:			
Gaseous	34,018	44,095	37,768
Liquid	44,125	42,080	25,620
Solid	35,350	33,390	31,080

Gaseous pyrolysis products contain 48-52% of hydrogen, 25-27% of methane (the other 20-25% is a mixture of hydrocarbon) and have a high calorific value (33-44 MJ / kg). (Production schedules of industrial plant for recycling of used tires with method of pyrolysis, 2006. 9.) Pyrolysis of gaseous fraction can used for extraction of aromatic oils suitable for the production of rubber compounds. Low molecular weight hydrocarbons can be used as raw materials for organic synthesis and as a fuel. Solid pyrolysis products (so-called tire ´´cox´´) are used in the treatment of waste water to separate ions of heavy metals, phenols, petroleum products. Technical carbon produced by pyrolysis, is used as the active ingredient in rubber compounds, plastics and paint industries. Liquid products of pyrolysis from waste rubber are also a high-quality fuel; it can also be for film-forming solvents, plasticizers, softeners for regeneration of rubber. Speck pyrolysis resin is a good softener, which can be used alone or in combination with other components. The heavy fractions of pyrolysis can be used as an additive to bitumen, used in road construction, and can improve its elasticity, resistance to cold and moisture. Apparatus for process of recycling of tires with method of pyrolysis shown in Figure 3.

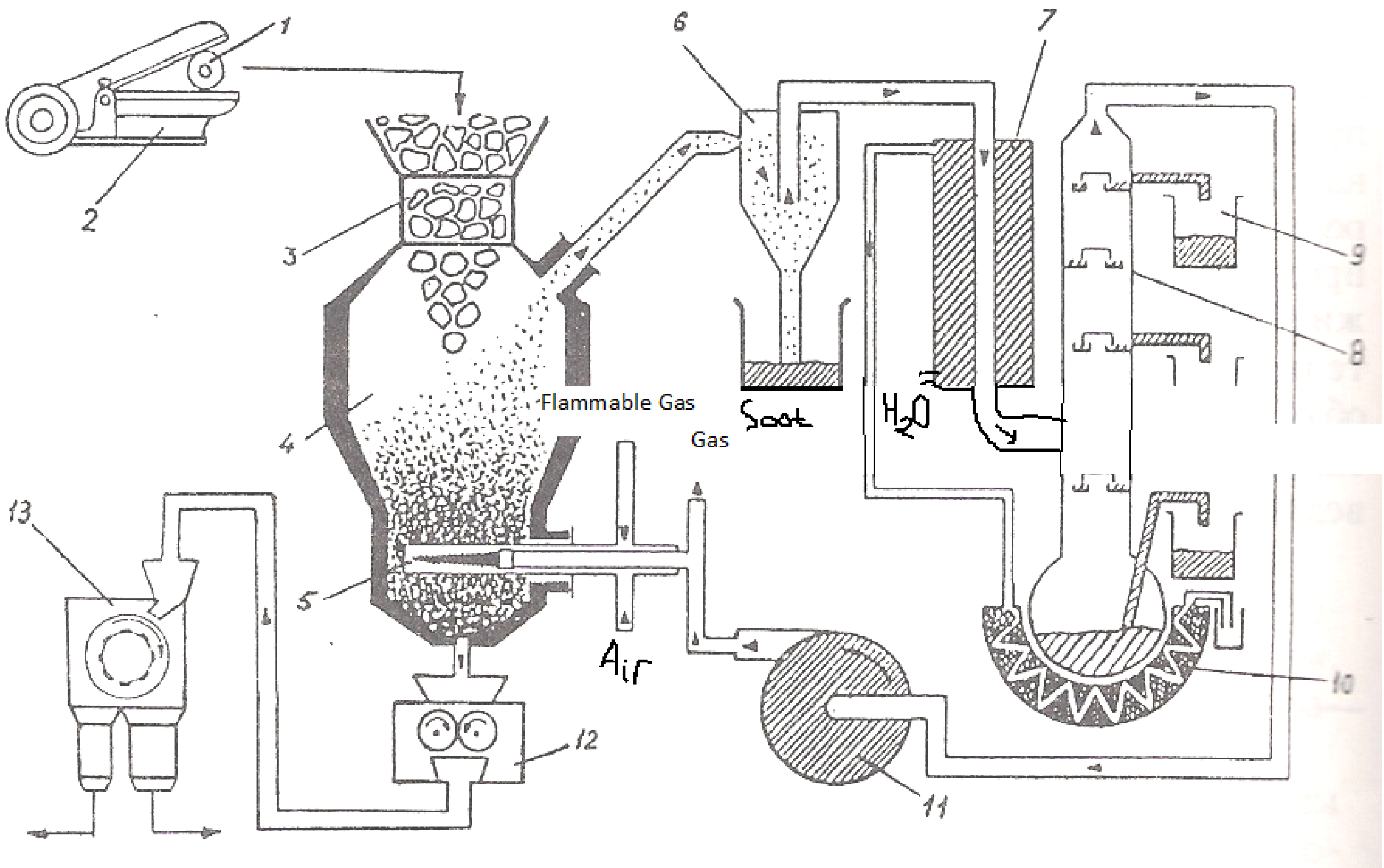


Figure 3. Setup of tire pyrolysis recycling (Source: Production scheme of industrial plant for recycling of used tires with method of pyrolysis, 2006, 54.)

1 - car tire 2 - guillotine 3 - boot device 4 - reactor, 5 - burner, 6 - cyclone 7 - refrigerator, 8 - distillation column 9 - capacitors collection, 10 - heat exchanger 11 - compressor, 12 – crusher of ´´cox´´, 13 - magnetic separator.

After washing used tires enter cutting machine 2, where they are cut into pieces (the size of 100-400 mm) and as such served in the bunker, and then fed to the boot device 3, which is equipped with reactor 4. There are systems where tires are loaded into the reactor without shredding. However, as the density of packing of shredded tires is not more

than 150 kg / m, some air gets into reactor and the pyrolysis process becomes more inefficient. The boot drive is a lock chamber with two gates that prevent ingress of air into the reactor. Downloading of pieces of tires is performed in cycles. The reactor is equipped with furnace 5 in which the burning natural gas is commenced, after which the stabilization of the pyrolysis it supported by the resulting pyrolysis gas. At the bottom of the reactor there is a device for discharging steel cord and the resulting cox.
Disperse pyrolysis products are removed from the reactor. Pyrolysis gas is produced in the cyclone 6, where the gas is separated from the solid particles such as soot. Gaseous fraction from the cyclone enters the refrigerator 7, which is cooled by circulating water; it condensates resins. Formed gas condensate mixture flows down to be separated in the distillation column 8, where it is separated into fractions by use of different boiling temperatures. The lower part of the distillation column is heated by hot water from the refrigerator in the heat exchanger 10. Pyrolysis gas from the distillation column (with the help of compressor 11) enters the combustion reactor. Excess pyrolysis gas is supplied to external customers, particularly for combustion to produce hot water and steam.
Solid phase - a mixture of ´´cox´´ and steel cord – after the discharge from the reactor enters the roll crusher 12 and is separated with magnetic separator 13. Steel cord is supplied to external user for further refining.

3.6 Other ways of using waste tires

Along with the utilization of using waste rubber, there are other, less effective possibilities for its disposal. Those usually do not require large capital investments, but bring only some benefit.
Used tires are also used to protect the coast structures from erosion, , artificial reefs, as side fenders and mooring shock absorbers, jetties, shockproof barriers on the roads, fences, etc. However, the secondary uses of this valuable material and energy resource is inefficient.

Late last year, near Minsk a retreading mini factory of JV "Belretred" was launched. It is placed in a restored truck tire technology company "Ellerbrok" (Germany). The essence of this technology is the use of a new pre-cured tread which is "glued" to the pre-prepared framework at temperature about 100°C. This prevents the possibility of secondary damage and allows curing of the tire carcass thanks to interaction between the rubber and cord. "Glued" in this case means "automatic cure", which is implemented by special chemicals that speed up the process.

The retreading process begins with visual inspection of the tires and results in the sorting tires with visible defects. This is followed by checking the tire with high pressure, after which the wheel comes to the site, where they remove the remains of the old tread.

After removal of small defects, the process of preparing the framework for processing adhesive follows. Then glue is applied (the glue is composed of substances that enhance the curing process), and after that the sealing tape, with composition like raw rubber. After all these operations the tire tread is processed by "Ellerbrok" process.

The next stage is laying the wheel to shell, called ´´envelope´´. The resulting "sandwich" is fed into the autoclave, where at temperatures below 100°C, the "cold vulcanization."

In Russia, the technology of cold vulcanization is also used in several companies. LLC "Sky", the dealer of a German company Vergolst operates in the North-West region. In Chekhov town there is a retreading plant called (CHSHZ) "Sovtransavto-Bryansk", which uses the technology of the U.S. company Bandag. In Kopeysk (city in Russia) there is a similar plant called RTI.

However, concerning passenger car tires, due to their widespread use, their repair is not always feasible, so it is advisable to dispose of them by granulating or utilize them as a secondary energy source.

4 ANALYSIS OF PRODUCTION FOR PROCESSING TIRES BY PYROLYSIS

4.1 Characteristics of processing plant

In that chapter I am going to explain main characteristics of old tire recycling machine (Constant-18M) at the factory where I was doing my research during my final thesis writing period.

The continuous growth of the car park leads to a constant increase in the number of used automobile tires. The problem of disposing of tires is present in megacities like Moscow and Moscow region, where the annual volume of waste tires is tens of thousands of tons.

Recycling of used tires by pyrolysis is carried out by using equipment called the "Constant-18M." The unit Constant-18M processes rubber waste to produce fuel gas and fuel oil. The main products of the installation "Constant-18M" is a high-quality fuel oil.

The principle of operation of the plant, "Constant-18M" is based on the method of thermal decomposition - pyrolysis. The term "pyrolysis" means the decomposition of organic materials in high temperatures without air, which drives the destructive transformations.

During pyrolysis process carbonization residues and gas-vapor mixtures are formed. Steam-gas mixture consists of vapor liquid pyrolysis oil, water vapor (pyrolysis water) and non-condensable combustible gases. Gas fraction is a mixture of different gases, extracted from the raw material and combustion process gases formed during the combustion of reverse gas heating.

The structure of the tire is a complex three-dimensional network. Its junction points are cross links between macromolecules of rubber. It is characterized by a few basic types of chemical bonds, carbon-carbon, monosulfide, disulfide, polysulfide and others.

In molecular chains there are side groups, consisting of molecules, vulcanizing agents and vulcanization accelerator, sulfur and oxygen compounds. When exposed to temperature influence the initial process of collapse of the vulcanized rubber break the weakest points in the spatial grid of the polymer chains. Such places are polysulfide, sulfide and oxygen bonds.

Decomposition products of the polymer chains enter into secondary reactions with each other, resulting in the formation of a low molecular weight and high molecular weight compounds, namely resins, heavy tarred residues and ``cox``. In this kind of technology, in order to maximize the yield of liquid fuels and particulate carbon we need to suppress secondary reactions. (Specifications for reprocessing of rubber waste "Constant 18M", 2006. 36.)

We used flue gases, which also enable the transfer of heat to the rubber raw materials and rapidly excrete breakdown of rubber products. Composition and physico-chemical properties of rubber suspension vary depending on the pyrolysis temperature, the gas pressure in the reactor and other process conditions.

The temperature corresponding to the maximum withdrawal of the liquid fraction (30-35%) is equal to 436 º C, was adopted as the optimum. The temperature range during process is 400-600 º C.

Products:

- Liquid fraction of 30-35%
- Pyrolysis gas is 10-25%
- The residual carbon is 20-30%
- Steel cord is 10%

Unencumbered by technical needs pyrolysis gas is removed from the unit through smoke line for flaring, or sent by pipeline to consumers. The plant is designed to operate in ambient temperatures from -30°C to +40°C. Average service life of the installation is 6 years. (Specifications for reprocessing of rubber waste "Constant 18M", 2006. 87-88.)

4.2 General characteristics and technical-economic indicators

The "Constant-18M" consists of three phases, including distillation, degassing and cleaning carbonaceous products. Two units are directly involved in the recycling process, and one link back is used when servicing the main links.

The main technical and economic indicators of production:

• Estimated annual capacity of the system to process used tires is 2500 tons per year

• Power supply: 380 V, 50 Hz

• Output power is 13,1 kW

• Estimated operation time of the reactor - 335 working days per year

• Daily production by feedstock (worn tires) - 6 t / day

Daily production yield, tons:

- Liquid fuel – 1,92

- Carbide materials – 1,45

- Metal – 0,6

- Gas - 1.08.

4.3 Flow sheet of production

The installation "Constant-18M" includes (Fig. 4):

Loading hopper (1) - consists of a metal box, divided into three parts with the mechanism for opening doors.

Gas expander (2) – is a device where gases are pumped out of the heater. At the exit of the expander there is a hatch to clean the chimney.

Reactor (3) - is a two-layer column (inside part of it is boot capacity) and (outside part is gas chamber).

Grate (4) - is a prefabricated tubular body having a plurality of insulation layers with holes for pyrolysis burners. The upper part of the grate is made of steel. Arrestor - prevents the passage of flames in the flue.

Gas burner (15) - is for burning of gases and more uniform heating of rubber raw materials.

Hopper discharge (5) - is a metal box that has the door, which opens at discharge screw drive.

Cyclone (6) - consists of a cylindrical tank with a conical bottom. Used for cleaning gases from large soot particles those are mixed with condensation.

Heat-exchange column (7) - is designed to condensate high boiling components and water from the gas mixture. The design of the column contains a body, lid and bottom.

Column fine (absorber) (8) - is assembled from pipe segments flanged column, filled with a special filler, to capture the lighter liquid fuel components in the gas mixture.

Demister (9) - serves as an additional deposition of aerosol particles of liquid fuel fraction.

Auxiliary exhauster (10) - is a high-pressure fan (working at the time of ignition of the reactor and output settings for optimal performance, and then it is turned off).

Main exhauster (12) - is a high pressure fan for moving the gas mixture in the cavities of pyrolysis unit.

Additional absorbers (11) - comprehend a column filled with special filler. Serve to capture the lighter liquid fuel components in the gas mixture.

Water separator (13) is designed to separate liquid-fuel components of the gas mixture, preventing the release into the atmosphere of the remaining volatiles.

Plunger (16) - is designed to create the optimum conditions during the process of pyrolysis.

Auxiliary exhauster (14) is located at the top of the silo discharge and serves to drain and clean the smoke out of the zone of discharge.

Crucible (17) - is used to unload steel cord and carbon residue.

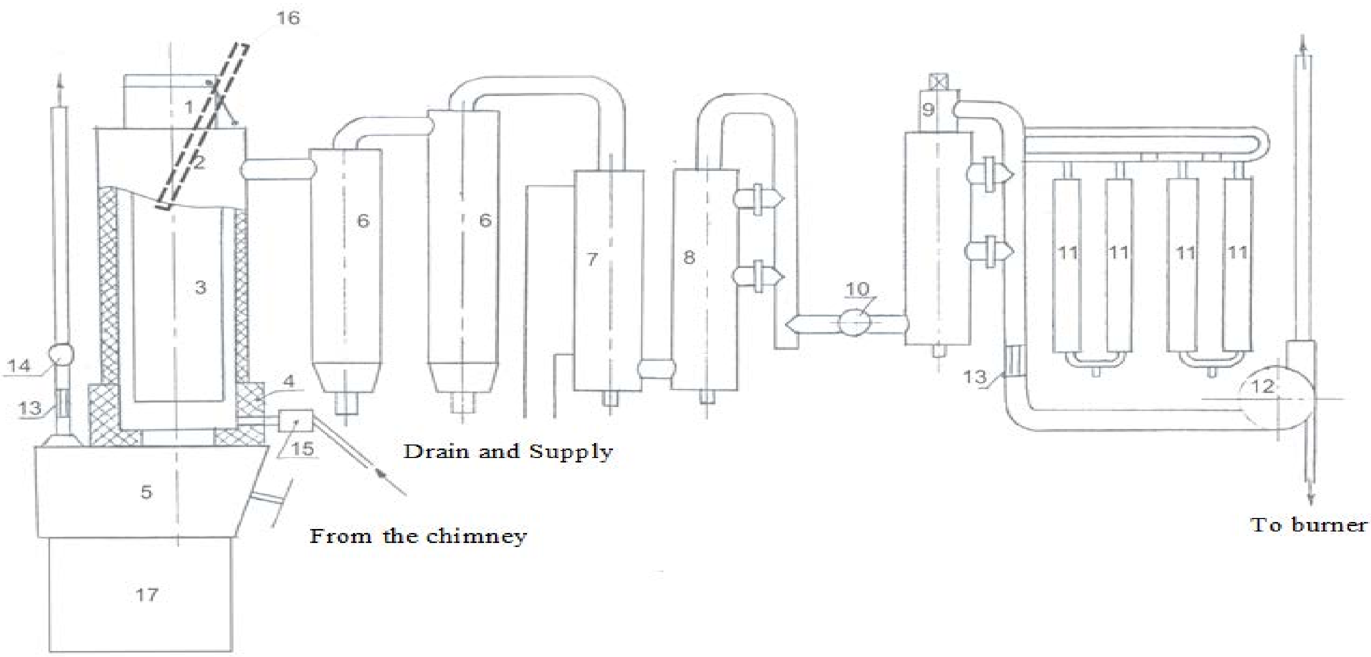


Figure 4. Technological layout of pyrolysis unit (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 44.)

Figure 5. Setting the "Constant-18M (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 2.)

Feedstock (used tires, inner tyres, and other rubber waste) is inspected for the detection of metal discs, rings. Rubber products are sent to be handled with a trolley to the area of raw materials preparation (cutting area) and to be loaded in the furnace reactor. On the site logging of raw material into small pieces is going on (size of a piece of $30 \cdot 30 \cdot 20$ cm) with special hydraulic scissors "Cayman 1500" (Fig. 6).

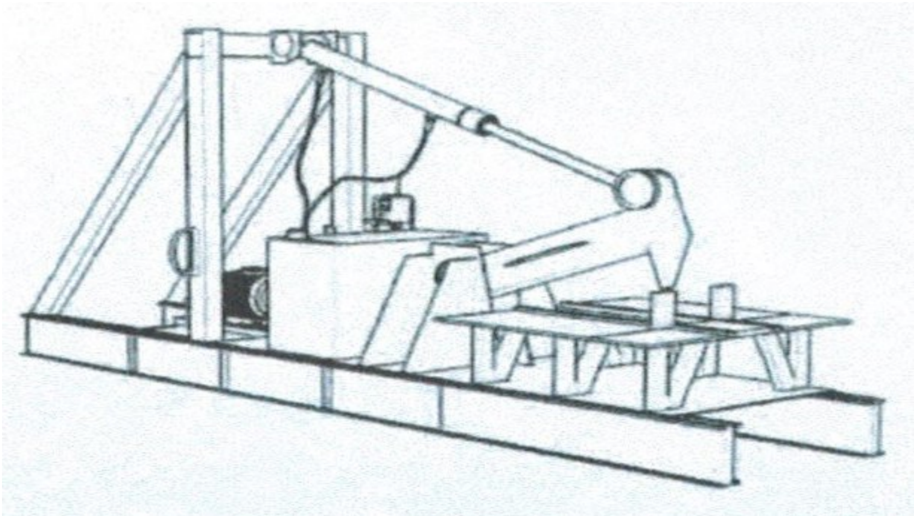


Figure 6. Shear "Cayman 1500" (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 6.)

Prepared raw material is loaded into a container that is using an electric hoist for raising it to the discharge hopper reactor (Figure 7)

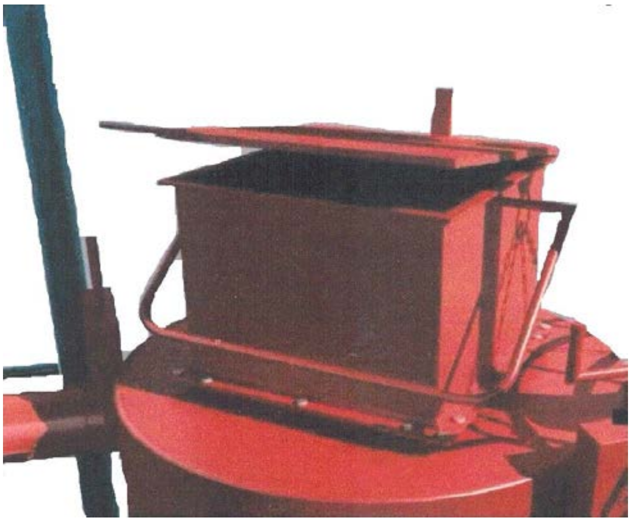


Figure 7. Reactor loading hopper (Source: Specifications for reprocessing of rubber waste "Constant 18M",2006. 9.)

Raised to the loading position, container interfaces with the open hopper loading hatch, then hatch of the container is released from clamps and opened and the raw materials poured into the drive. Hourly feeding of material in the reactor is 2-3 containers. In the bunker, under the weight of the loaded material, the door is opened and the rubber falls in the middle of the bunker. At this point, due to the reverse mechanism, door closes automatically, etc. Filled bunker is locked and unloaded in a closed reactor. In the pyrolysis process the material must be loaded uninterrupted. Hopper load is the gateway, preventing access of oxygen to the top of the column.

Process (pyrolysis) goes on in reactor with temperature of 400-600 º C. According to the results of the pilot launch this temperature range allows for maximum yield of liquid hydrocarbons. Temperature control is carried out by a temperature sensor (thermocouple). In the process of pyrolysis intermediates are derived: gas-air mixture, pyrocarbon and metal residue.

Gas-vapor mixture at a temperature of about 150-200 º C under the pressure is created by the exhauster. It is fed into the cyclone where it is cleared of large particles of soot, which, by mingling cause condensation of heavy hydrocarbon fractions. Deposited in the bottom with natural flow they are removed through ball valve once every 1-1,5 hours.

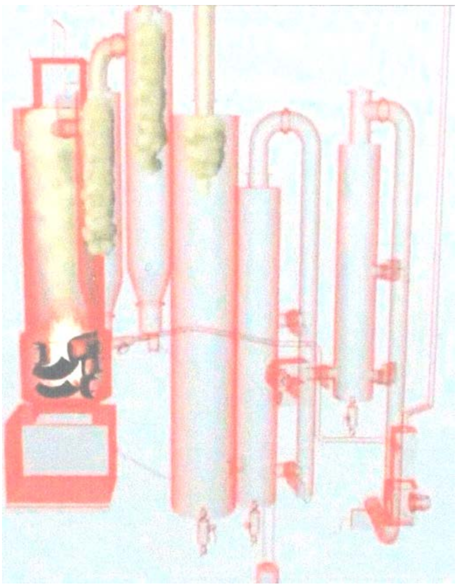
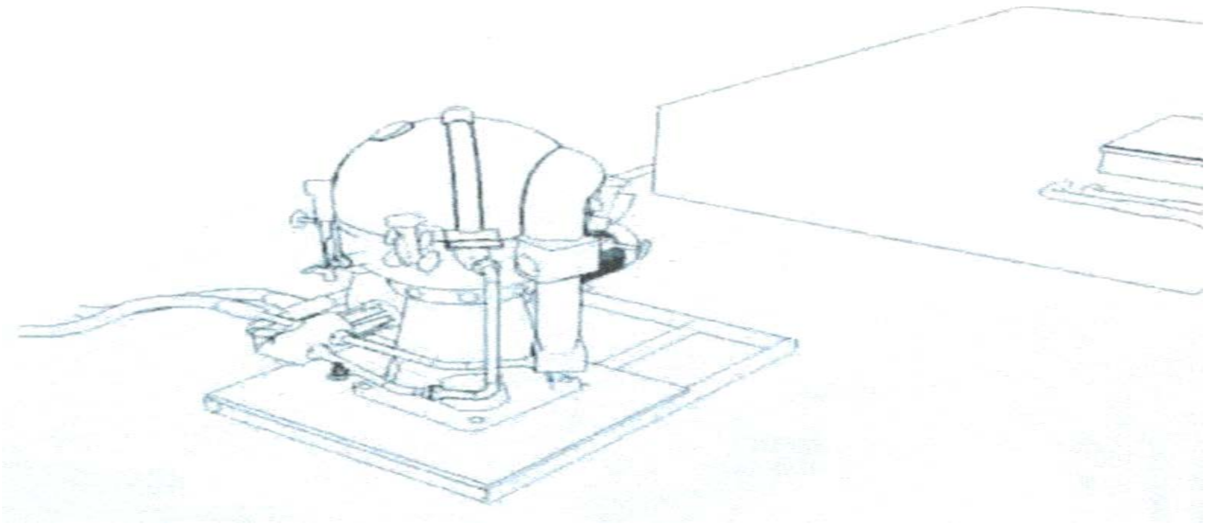


Figure 8. Layout of discharge gas mixture (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 48.)

Further gas-vapor mixture at a temperature of 100-120 º C passes through the heat exchangers. It is cooled to 50-70 º C, resulting in a mixture of condensed high boiling components. Cooling of heat-exchange towers is achieved by circulating water (water volume of 3 cube meters); water intake for cooling system is taken from the centralized water supply and equals to 0.15 cube meters. In cold weather, water in the heat exchanger cannot be used.

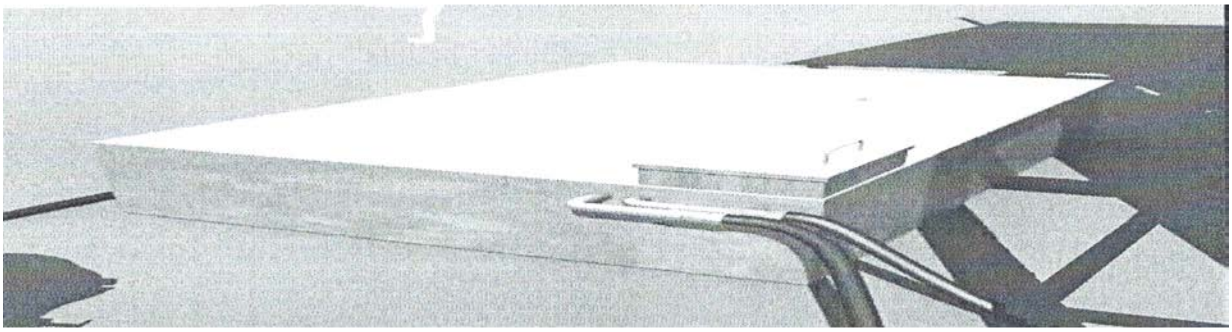
Air-gas mixture passes through the adsorbers designed for fine mechanical purification and recovery of the lighter liquid fuel components in the gas mixture. At the top of the canister a demister is installed. Gas-vapor mixture from the heat exchanger is fed to the bottom of adsorber and goes to the demister (aerosol separator), where the liquid fuel components in the form of aerosols are condensed into droplets of liquid fuel and flow by gravity back to the top of the canister. Temperature gas mixture at the outlet of adsorber is 20-30 º C. After adsorbers gas-vapor mixture goes to oil separator (OS 08.00.000) where liquid fuel components are separated. Movement of gas mixture in the cavities of pyrolysis unit is generated by the primary pressure and secondary smoke exhauster.

Auxiliary exhauster works together with the main exhauster at ignition of the reactor and outputs settings for optimal performance, and then the auxiliary exhauster goes off. At the exit of the main exhaust fan pyrolysis is divided into two streams. One part goes back in smoke line to the furnace reactor and helps to keep process of pyrolysis in permanent status. Another part of the pyrolysis gas is released through a pipe (it is also possible to feed the remaining amount of pyrolysis gas to close-consumers). Adsorbers and gravity moisture separator feed the substances the primary container (Fig. 10) with 3 cube meters volume and by the piping system are connected to oil cleaner (Fig. 9), where they are subjected to purification of water and solids.



(Figure 9) Oil Cleaner (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 56.)

After oil cleaner processing liquid hydrocarbons are coming to secondary body capacitance. It comprehends two tanks with volume of 3 cube meters each, connected by a jumper. With help of the ball valve it is possible to cut off the primary receptacle and repeat the cleaning process of liquids in a closed loop (oil cleaner - a secondary container). Purified liquid hydrocarbons go by pipe system to the storage of liquid fuel in underground tanks (50 cube meters).



(Figure 10). The primary receptacle (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 59.)

Metal residue and pyrocarbon are unloaded from the reactor into the crucible, tightly placed at the bottom of the hopper discharge (Figure 11). Air is drawn from the (hopper discharge fan) that faces adsorber with ´´Raschig rings´´ and oil separator OS 08.00.000.

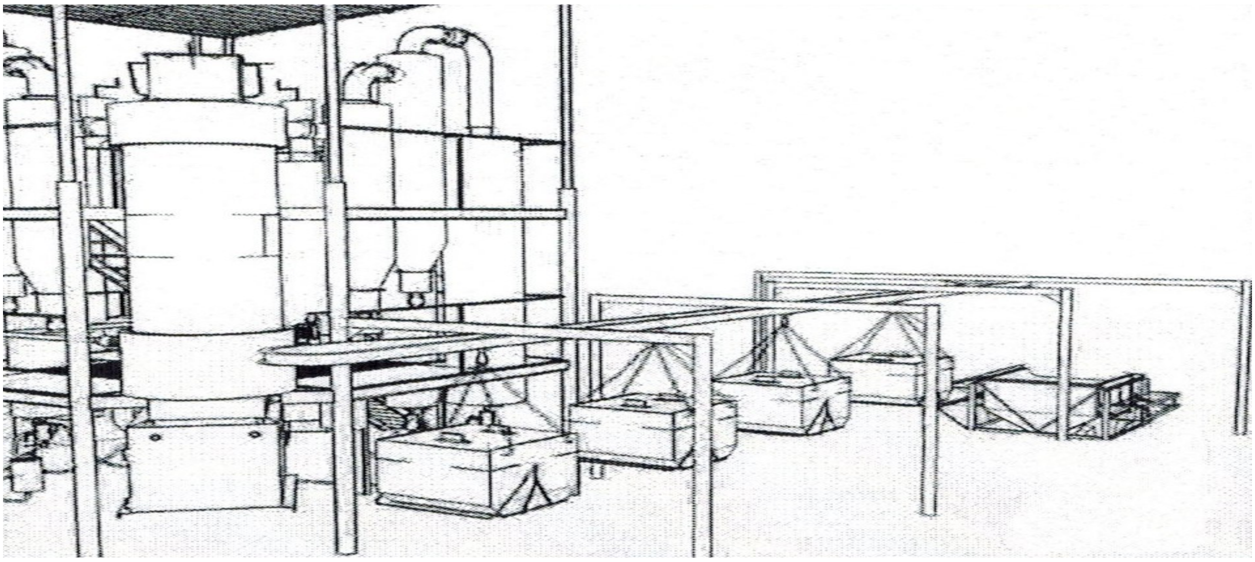


Fig.11 Pyrocarbon unloading system and metallic residue (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 62.)

After cooling process pyrocarbon goes to magnetic separator to separate the metal residue. Separated metal residue is sent to a temporary storage tank. After that with a hydraulic press metal residue is pressed into briquettes, which are sent to the temporary storage of scrap for onward transmission to the consumer. Pyrocarbon is loaded in a shaker (Fig. 12) and then with screw conveyor it is fed to the mill (SB-124A) for grinding. To eliminate dust in mill there is an air ventilation system. It is followed by purification of the battery cyclone BTSSH - 200. Caught in a cyclone fine particles are added to the mill grinding and to pyrocarbon. The resulting pyrocarbon is packed in sealed bags and transferred to the consumer. The output of products in the processing of rubber waste (daily productivity - 6t/day.) is:

- Liquid hydrocarbons - 47%;
- Pyrocarbon - 20-30%
- Pyrolysis gas - 13%;
- Metal residue - 10%.

(Fig.12) Shaker (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 69.)

Purpose and description of the appearance of the resulting products of the pyrolysis are shown in (Table 6) below:

Table 6 Purpose and description of the appearance of the resulting products of the pyrolysis (Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 60.)

Name of products	Layout	Purpose of production
Pyrolysis liquid fuel	Dark, oily liquid with a characteristic smell of oil. Black, with a slight brownish tinge. Partially soluble in water (up to 20%). Flash point (not less than 68 º C).	Used as a liquid fuel for boilers, heating oil substitute. Applicable distillation into fractions in order to obtain various petroleum products (gasoline, diesel fuel, oil, resin, etc.)
Carbonaceous solid residue	The main mass is a crumb of 0,5-3 cm, with individual particles up to 6-9cm, partly (25%) is destroyed, the edge break off. Color - black with gray shade. The structure is porous.	Is used as a solid fuel, and can be used for production of modified liquid fuel, as a sorbent, replacement of activated carbon as a filler in the manufacture of new rubber products.
Pyrolysis gas	Colorless, with a light mist of white shade, with a smell of char. Humidity up to 20%. Able to burn when heated at temperatures above 110 º C.	Used partly to 40% for the installation, the rest after burned to heat generators or flares.
Scrap (metal)	It is like a cutting wire. Due to possible high temperatures, the metal surface color is dark brown. It can be pressed well.	It is composed of high-quality steel. It is used for further metal processing.

4.4 Calculation of emissions from the installation Constant 18M

All of the needed formulas and primary data were given by scientists from the company I worked for.

$M_i = 3600 \cdot 10^{-6} \cdot G_i \cdot t \cdot N_i$

$G_i = 0{,}001 \cdot K_i \cdot Q$,

where

M_i - total emission of pollutant (i) (t/year)

G_i - maximum one-time emission of pollutant (i) (g / s)

t - time of work selected pollutant (i) (day/hour)

N_i - The number of working days of the source selection (i)-pollutant per year

K_i - Concentration of pollutant (i) (g/s)

Q - Consumption of gas-air mixture m ^{3} /s,

Sources of Pollution:

Harmful: sulfur oxides (calculated as SO2)

$G = 0{,}001 \cdot 206{,}3 \cdot 1{,}05 = 0{,}2166\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}2166 \cdot 24 \cdot 335 = 6.2693\, t/year$

Harmful: nitrogen dioxide

$G = 0{,}001 \cdot 310{,}2 \cdot 1{,}05 = 0{,}3257\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}3257 \cdot 24 \cdot 335 = 9.4273\, t/year$

Harmful: petrol

$G = 0{,}001 \cdot 23{,}5 \cdot 1{,}05 = 0{,}0247\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}0247 \cdot 24 \cdot 335 = 0{,}7149\, t/year$

Harmful: kerosene

$G = 0{,}001 \cdot 36 \cdot 1{,}05 = 0{,}0378\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}0378 \cdot 24 \cdot 335 = 1{,}0941\, t/year$

Harmful: formaldehyde

$G = 0{,}001 \cdot 6{,}135 \cdot 1{,}05 = 0{,}0064\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}0064 \cdot 24 \cdot 335 = 0{,}1852\, t/year$

Harmful: phenol

$$G = 0{,}001 \cdot 5{,}01 \cdot 1{,}05 = 0{,}0053\ g / \sec$$

$$M = 3600 \cdot 10^{-6} \cdot 0{,}0053 \cdot 24 \cdot 335 = 0{,}1534\ t / year$$

Harmful: carbon monoxide

$$G = 0{,}001 \cdot 200{,}5 \cdot 1{,}05 = 0{,}2105\ g / \sec$$

$$M = 3600 \cdot 10^{-6} \cdot 0{,}2105 \cdot 24 \cdot 335 = 6{,}0927\ t / year$$

Harmful: carbon black

$$G = 0{,}001 \cdot 263{,}0769 \cdot 1{,}05 = 0{,}2762\ g / \sec$$

$$M = 3600 \cdot 10^{-6} \cdot 0{,}2762 \cdot 24 \cdot 355 = 7{,}9943\ t / year$$

The results of the calculation in emissions (by source) Table 7

(Table 7) Calculation of emissions from the installation Constant 18M

Harmful substances	Total emissions before cleaning (t/year)	Concentration of pollutant (g/s)	Consumption of gas-air mixture (m^3/s)	Time of work selected pollutant	The number of working days	Maximum one-time emission of pollutant (g / s)	Total emission of pollutant (t/year)
SO2	10,0309	206,3	1,05	24	335	0,2166	6,2693
NO2	15,0836	310,2	1,05	24	335	0,3257	9,4273
Petrol	1,1438	23,5	1,05	24	335	0,0247	0,7149
Kerosene	1,7506	36	1,05	24	335	0,0378	1,0941
Formaldehyde	0,2963	6,135	1,05	24	335	0,0064	0,1852
Phenol	0,2454	5,01	1,05	24	335	0,0053	0,1534
Carbon Monoxide	9,7483	200,5	1,05	24	335	0,2105	6,0927
Carbon black	12,7909	263,0769	1,05	24	335	0,2762	7,9943

(Source: Specifications for reprocessing of rubber waste "Constant 18M", 2006. 66.)

Disadvantages of Constant-18M:

- A continuous process (since the launch of the process is very time-consuming and energy-consuming)
- Work with an open fire. When unloading carbide residue its suppression should be carried out at the end of the process of pyrolysis and temperature should be reduced, due to the continuity of the process
- Frequent crashes of installations
- Falling production quality
- Recently, accidental releases
- Replacement of ´´Raschig rings´´ (costly)
- Cutting tires into smaller pieces involves the use of additional techniques (magnetic separator) - spent additional electricity.

Therefore, together with engineers and environmentalists led by the director of the company, it was decided to be replaced by system with more modern and appropriate environmental parameters.

5 DEVELOPMENTS FOR IMPROVING THE EFFECTIVENESS OF RECYCLING PLANT

5.1 Key features and the principle of operation of the plant Ecoenergetik

Given the existing difficulties and shortcomings in the working process of "Constant 18M" was decided to upgrade the installation. At the end of the meeting of members from LLC "Istra Ecology" and, after a preliminary calculation of the environmental emissions from the proposed facility a final decision on the implementation of the installation Ecoenergetik was made.

The principle of operation of the plant is to use a thermal decomposition of waste rubber - carbonization. It is decomposition of organic matter by heat without air, resulting in a destructive transformation. During carbonization a solid residue and gas-vapor mixture was achieved. Steam-gas mixture is composed of vapors of flammable liquids and condensable combustible gases. Gas fraction is a mixture of different gases identified in the thermal processing of raw materials. The main production facility is in the form of products: liquid fuels (solvents), high-solid residue (carbon), scrap metal and gas.

Specifications of the system Ecoenergetik is shown in (Table 8) below:

(Table 8) Specifications of the system Ecoenergetik (Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013.7.)

Number retort furnaces, unit	1
Number of retorts, unit	2
The nominal volume of the feed chamber, m3	2,6
The installed capacity of power	1,1kW
Rated voltage	380V
Rated frequency	50Hz
Unit weight (with two retorts)	4700 kg
Installation height (with pipes)	5,6m

5.2 Description of technological process (pyrolysis) to install Ecoenergetik

Raw materials (used tires, etc.) are loaded into a vessel of heat-resistant material (retort). The retort is placed in the oven. Raw material is heated by heat transfer through the walls of the retort and subjected to thermal decomposition (pyrolysis) to form a mixture of steam and carbon residue - char. Steam-gas mixture derived from the retort through a pipeline cools, vapor condenses and the resulting liquid is separated from non-condensable gases. Fluid builds up in the collection of the liquid product. Gas is partially or fully used to support the process (burned in the oven). At the end of the pyrolysis process, retort with char is removed from the oven and set to the oven retort with raw materials. Installation of Ecoenergetik consists of the following units:
Retorts, isobaric bellows, steam-gas line pyrolysis, capacitors, refrigerators, downtank separator liquid products, gas-liquid separator, furnaces, burners, injector, blower, chimney caps retort. Scheme of instalation Ecoenergetic plant is shows in (Figure 13).

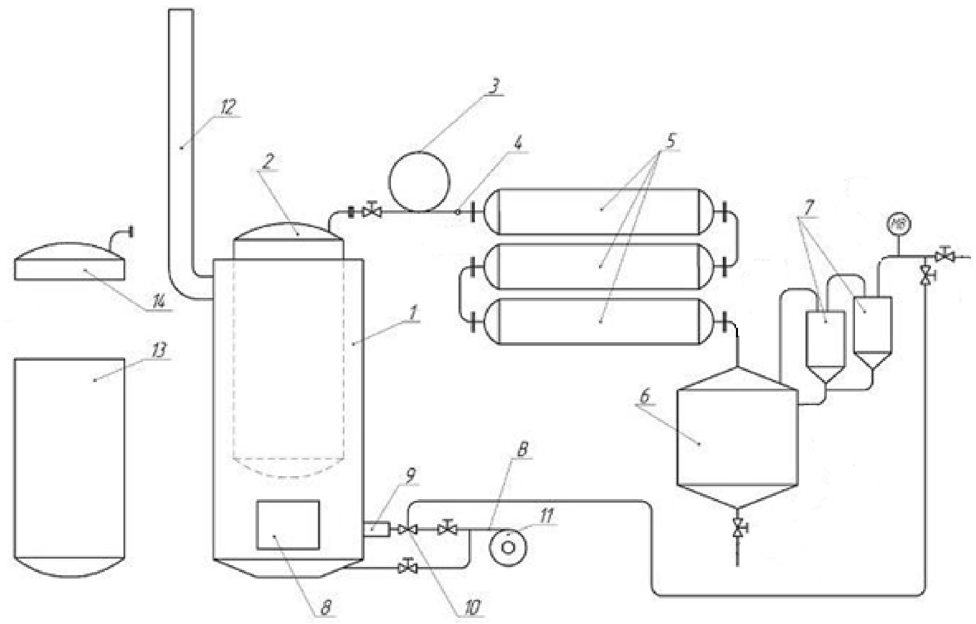


Figure 13 Scheme of instalation Ecoenergetic plant (Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 2.)

1 – battery of retort furnaces, 2-retort from stainless, 3- silfon, 4- header pipe of steam (gas pyrolysis), 5- refrigerators, 6-downtank- separator, 7-gas-liquid separators, 8-combustor, 9-Gburner, 10- jetpump, 11- blowing machine, 12-chemney, 13- Retort in loading and unloading, 14- cover of retort.

Retort oven - shaft of furnace lined with refractory concrete and based ceramic fiber high thermal insulation. In the lower part of the shaft furnace is installed grate for burning solid fuel and burner device for burning combustible gases. Intensification of combustion and mixing of flue gas is achieved by air pressurization. In the shaft through the open top of the shaft is placed retort with raw materials. Retort - a cylindrical container of heat-resistant steel, with lid. Special bolt mating surfaces on the perimeter gives pressurization of seals in interior of the oven. Capacitor-refrigerator designed for cooling and condensation of liquid pyrolysis products. Steam-gas mixture flows from the retort to the condenser-cooler via a quick connection and expansion bellows. Condensable and non-condensable gases are piped to the collection separator. It is a cylindrical container used to collect liquid products of pyrolysis and partial capture splashes of liquids from the gas stream.

The final cleaning of the gas from the liquid droplets is carried out in the gas-liquid separator. Fuel gas enters the burner and / or other users. Retort furnace is loaded with raw materials in a horizontal or vertical position. After loading, the retort lid is closed. Loaded retort set in the oven and with quick connection to the pipeline connects the cooler-condenser. Converter can be installed in a hot and in the cold oven. For the burning purposes solid fuel (wood, coal, and char) is loaded onto a great furnace door and ignited. Intensification of combustion air is provided by a supercharged under the grate. The intensification of the mixing of gases in the furnace and the furnace temperature control is provided by supercharged air through the air nozzle of the burner.

Pyrolysis gas enters the burner and ignites. The end of the pyrolysis process is determined by the decrease in the flow of gas. To obtain a high-quality ´´semi-cox´´ process is conducted until putting an end to gas flow ("drying"). Semi-cox process is pyrolysis process of carbonaceous materials and it occurs in low-temperature carbonization. After that flow stops for about 30 minutes. Next step is to lower the temperature. After that temperature in retort is brought down by quick disconnection of pipeline of the cooler-condenser and reposition to the loaded retort. The extracted hot retort cools the air. After cooling the retort lid is opened and offloaded to char rollover. (Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 9.)

Refractory concrete and ceramic fiber linings are used for high durability and longevity of the furnace. It is designed to last at least 10 years, in contrast to the furnace by ordinary steel (design life of which not more than six months). Concrete lining is maintainable. At the end of use worn lining can be replaced. Aspiration can efficiently burn low-grade fuels and minimize heating furnace. Retort from heat resistant steel is highly resistant to the altering conditions of use and has low weight. Movable retort furnace allows operation almost continuously, allowing setting and retrieving the retort. The cooling of the char in closed retorts with air flow eliminates cooling of char with water and reduces environmental problems. Unloading with rollover eliminates the cumbersome, slow and dangerous to the health manual unloading. Movable retort is maintainable and allows replacement the most intensively exposed part - the bottom. Steam-gas pipelines and fridge condenser are made available for treatment of possible deposits.

Before starting of the burning it is necessary to shade perimeter of the concrete abutment grate furnace lining, pour a layer of slag (the small brick) to a height of about 50 mm. Slag layer should overlap approximately 100 mm as gridiron as well as adjacent to it a concrete lining. The central part of grate should remain free. Four hours before the end of the initial warm-up screening should be removed. Originally oven is heating without boost. In the case the heating starts to go down, boost switches on and regulates air flow restrictor from the minimum speed. It is necessary to maintain a steady slow rate of temperature rise before the concrete lining and metal retort are heated up at the end of the initial warm-up.

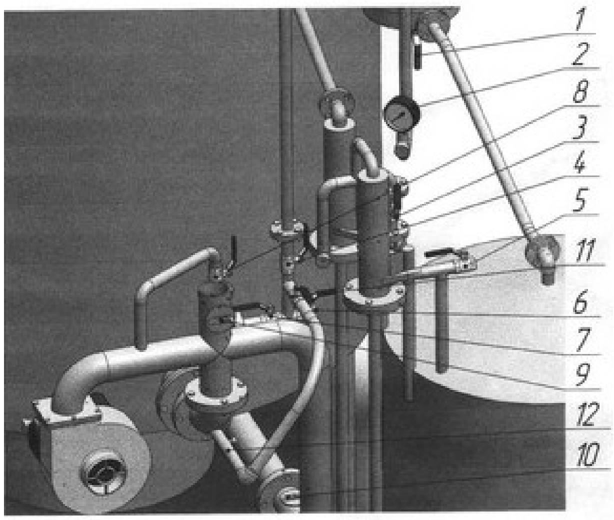


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Fig. 14 The tube manometer (Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 17.)

Before you start installation, you must add water to the tube manometer (Item 2) (Fig. 14). Manometer after pouring water shows zero pressure. The retort is loaded outside the furnace in a horizontal or vertical position. Converter can be installed in a hot or in a cold oven. Diameter of the retort is 1 m 15 cm, so even the whole European truck tires can be fed in without cutting. In order to increase the loading density, installation goes with debeading machine. Beads of tires are cut from two sides with debeading machine and placed in the middle of the tread portion. Loading density increases significantly and, therefore, more raw material can be processed. Advantage of this technology is also that metal cord is not cut and at the end of the pyrolysis process it is much easier to separate the steel cord from carbon.

After loading process, the retort lid is closed. Loaded retort is set in the oven. Steam-gas pipeline should be connected to the pipeline of the retort condenser-cooler. During each loading process, operator needs to pay particular attention to the lack of carbonized pipeline gas outlet on the fridge, keeping an eye on when it is necessary to clean it.

The cooling water of the condenser-cooler is turned on. Valves 1, 3, 5, 7, 8, 11 are closed, 4 and 6 are opened and air regulator burner 12 should be inserted completely.

Solid fuels (wood, coal, char) are downloaded to the furnace grate and ignite. Ash door is open and the oven door is closed. During the pre-heat of the oven it is necessary to heat for an hour under natural draft and keeping the fuel layer on the grate (to char - about 10-15 cm). After one hour, the fan is turned on. With the throttle 10 the intensity of the air blowing is adjusted and gradually increased. Throttle 9 restricts the air pressure in the blower fan to prevent overloading. Simultaneously air regulator of the burner (nozzle 12) is activated at 10-15 mm for gas circulation in the oven.

Periodically the flame is removed (closing nozzle 10), the presence of hot concrete lining and metal retort are observed. Colors should be no brighter than dark red. Upon reaching the deep red-color one has to reduce (throttle 10) temperature. During heating process of furnace and retort, gassing goes out from the tap 6. By closing tap 6 and opening tap 7, pyrolysis gas enters to the burner and ignites.

Regulator 12 circulates gases in the furnace, generates the desired temperature of the combustion products, providing correct smoke point (most advanced mode corresponds to 2-8 mm regulator). With the increase of the heat input of a gas flame, one needs to reduce and then completely stop blowing process under the grate (nozzle 10). To complete the process of pyrolysis one needs to use solid fuel. To protect the grate from overheating and to reduce heat loss, it is necessary to maintain a layer of ash on the grate (should be about 10 cm). Temperature in the furnace is controlled by color. The gas pressure in the retort is controlled with (manometer 2). Allowable pressures - not more than 7 kPa. In the initial period after the 3kPa pressure, the (tap 3) is opened to reduce the resistance of separators. The pressure in the retort is controlled by varying the power to the furnace. Due to the high heat capacity of the furnace it should be controlled with a lead of 15-20 minutes. Upon reaching 5kP, pressure should be reduced by reducing the capacity of the furnace blast air under the grate (solid fuel) and / or reduce the supply of gas to the main burner flame (gas). Dumping of excess gas needs to be adjusted with (tap 6). In case of excess of pressure 7kPa excess gas is lost with (tap 5). With the completion of the pyrolysis process gas pressure goes down too. When reducing the gas pressure to less than 3 kPa tap 3 is closed for efficient operation of separators.

The pyrolysis process is complete when the amount of gases is not enough for the burner. After the extinction of the flame, by closing taps 8, 7, 11, and opening taps 3, 4, 6, the residual gas is cleared and the fan turned off. Before removing the retort we should reduce the temperature in the furnace. Removing the retort during visible incandescence is unacceptable. Oven temperature is reset by cooling the air with natural draft. After the extinction of the flame, the ash door is closed, the oven door slightly opened (air gap of about 30 mm) and it is allowed to stand for about 45 minutes. After cooling, the oven must be disconnected from the steam-gas pipeline of the retort condenser refrigerator. The retort is extracted from the furnace and placed vertically in a special area for cooling. Immediately after removing the retort oven is set to retort with raw materials. Time between the removal and installation of the retorts must be minimized in order to avoid contact of warm heat of liner with cold air. Amount of liquid (pyrolysis oils), as well as other substances derived from processing waste pyrolysis plant Ecoenergetik, depends on the characteristics and composition of the feedstock. Recycling of used tires, at the end of the pyrolysis products are formed (Fig.15):

- 41% of pyrolysis oil
- 10 to 12% of pyrolysis gases
- 8 to 10% of steel
- 40% carbon black

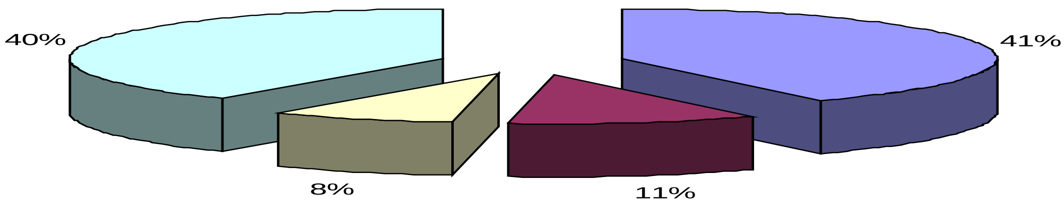


Figure 15. Products resulting from the pyrolysis process from used tires (Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 3.)

Pyrolysis oil

It is used as fuel for industrial furnaces, boilers, heat generators equipped with spray burners. It is a better quality analog then heating oil, surpasses it in its characteristics and properties. Heat capacity is 25-30% higher, it has a much lower viscosity and does not freeze at a temperature of -35C. Pyrolysis oil can be used in boilers without further processing and conversion plants themselves. It is also applicable in distillation into fractions in order to obtain various petroleum products like (gasoline, diesel fuel, oil, tar, etc.).

Characteristics of pyrolysis oils:

Density at 20 ° C	913,7 kg / m ³
Content of ash	0,28%
Mass fraction of water	0,5%
Sulphur	1,041%
Temperature of flash point	21 °C
Freezing temperature	- 35 °C
Lower calorific value	39 500 kJ / kg
10% distilled at	130 °C
90% distils at	360 °C

(Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 24.)

Carbon black

It is used mainly in the tire industry. Rubber gives high wear resistance, tear resistance and tear strength, high strength and low hysteresis. Widely used to produce high quality rubber tread for all types of vehicles and tread blanks for recovery of agricultural machinery, conveyor belts. Used as a solid fuel (1 kg of carbon residue replaces 1.34 cube meters of natural gas). It is used in the production of abrasives, as well as installations for waste water treatment, after additional calcinations can be used in the electrode mass.

Characteristics of carbon:

Density	430 kg / m ^{3}
Ash	7,4%
The maximum mass fraction of total moisture	5,4%
Sulphur content	1,3%
The mass fraction of carbon	96%
Volatile	0,09%
Calorific value	30 000 kJ / kg

(Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 25.)

Pyrolysis gas

Used partially and / or fully for workability of installation.

Characteristics of pyrolysis gas:

Density	1,1 kg / m
Calorific value	8700 kJ / kg
Nitrogen content	25-35%
Mass fraction of hydrogen	15-20%
Mass fraction of the carbon monoxide	15-25%
Mass fraction of methane	5-10%
Moisture	15-20%

(Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 25.)

5.3 Proposals to increase the efficiency of the plant Ecoenergetik

During my writing process in Moscow I would like to make suggestions to improve the efficiency of the plant Ecoenergetic.

The suggestion include that the most effective way is to work on two or more of pyrolysis furnaces at one time, because excess gas from the first furnace can be used to heat the second. In each period of time furnaces are in different stages of the process. Phase shift between the two furnaces process chosen so that the second wave is going through a maximum gas production at a time when the first wave is in greatest need of fuel.

Shown in (Figure 16) is a schematic setup of the pyrolysis furnace of Ecoenergetic plant. The estimated annual capacity of the unit from one of the pyrolysis furnace for raw materials is 1005 tons / year. All of the needed formulas and primary data were given by scientists from the company I worked for.

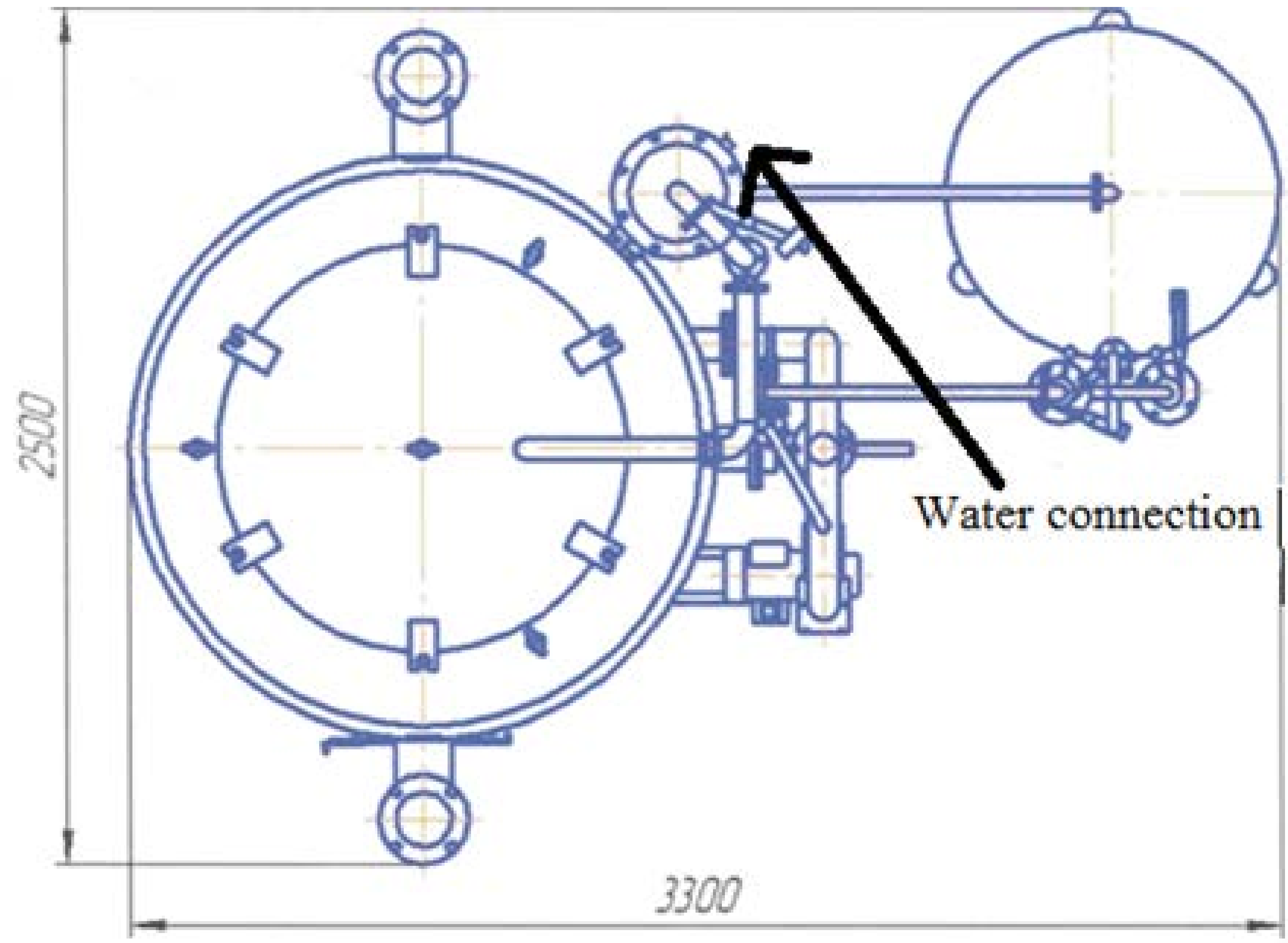


Figure 16. Figure of one of the pyrolysis furnace Ecoenergetic. (Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 33.)

Installed performance of recycling raw materials (P_1) and yield (P_2) is determined by calculations:

$P_1 = K \cdot V \cdot P$,

where

P_1 - plant capacity (tons / shift)

K - the load factor (K = 0.6)

V - the volume of raw materials of the furnace - the reactor, P_1 (2.5m^3)

P - the proportion of raw materials, t/m3 (0.670 t/m^3)

$P_1 = 0{,}6 \cdot 2{,}5 \cdot 0{,}670 = 1{,}005$ t/shift

$P_1 = 1005(t/year) \div 335(days) = 3(t/day)$

$P_2 = P_1 \cdot F$,

where

P_2 - the capacity of the unit to release the finished product (t/shift)

F - yield coefficient (F = 0.9)

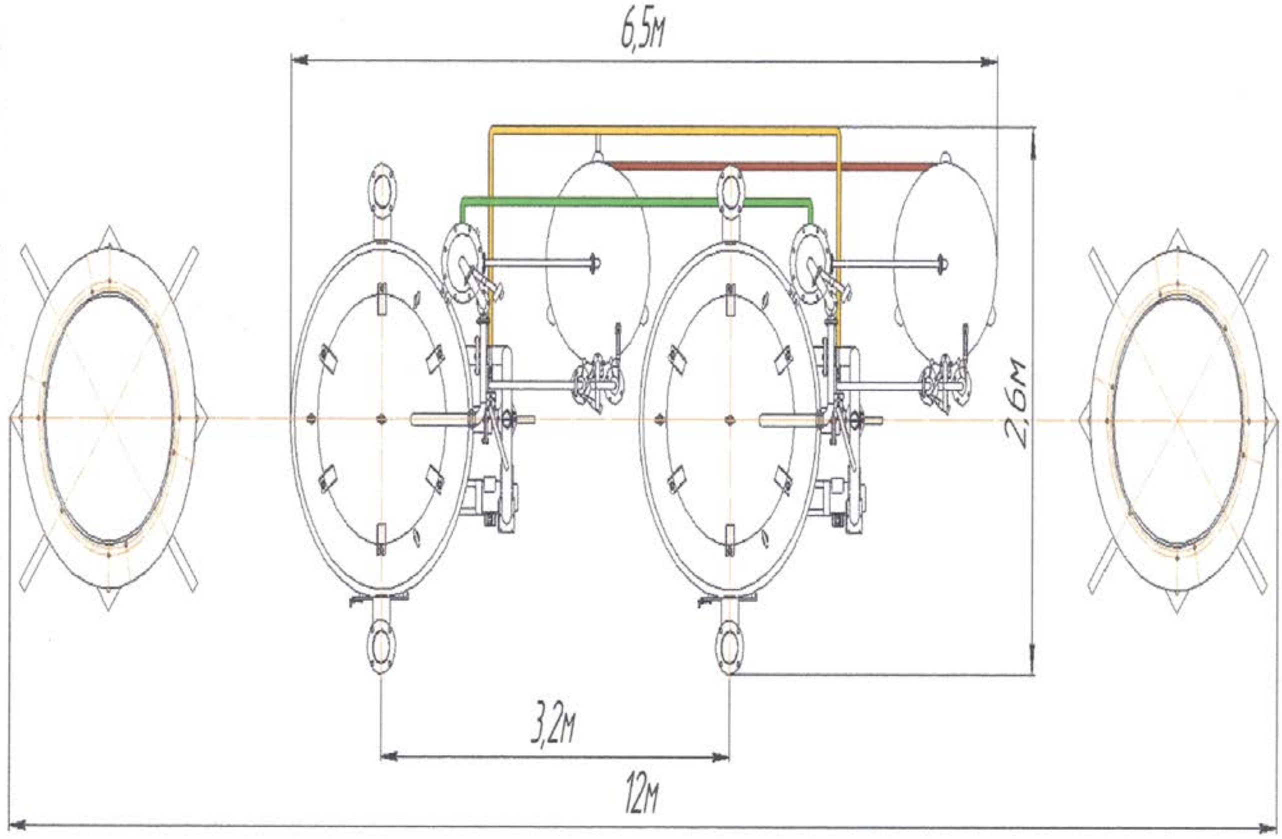
$P_2 = 1{,}005 \cdot 0{,}9 = 0{,}940(t/shift)$

During pyrolysis process produced the following products:

- The liquid component of the fuel oil fraction (40%) - 0.376 tons / shift;
- High solids content (40%) - 0.376 tons / shift;
- Ferrous metals (8%) - 0.075 tons / shift;
- Pyrolysis gas (12%) - 0.113 tons / shift.

I decided to calculate how much the performance would be increased when using two pyrolysis furnaces. The experimental setup with two pyrolysis furnace is shown in (Figure 26). The estimated annual capacity of the unit of raw material for the simultaneous operation of two pyrolysis furnace will be 2010 tons / year. Install performance for recycling raw materials (P1) and yield (P2) is determined by calculations:

(Figure 17). The experimental setup with two pyrolysis furnaces



(Source: Specifications for reprocessing of rubber waste "Ecoenergetic", 2013. 35.)

$P_1 = K \cdot V \cdot P$,

where

P_1 - plant capacity $(t / shift)$

K - the load factor (K = 0.6)

V - the volume of raw materials of the furnace - the reactor, P_1 ($5m^3$)

P - the proportion of raw materials, t/m3 (0.670 t/m^3)

$P_1 =$ 0,6 $\cdot$ 5 $\cdot$ 0,670 =2, 01 t/shift

$P_1 = 2001(t / year) \div 335(days) = 6(t / day)$

$P_2 = P_1 \cdot F$,

where

P_2 - the capacity of the unit to release the finished product $(t / shift)$

F - yield coefficient (F = 0.9)

$P_2 = 2{,}01 \cdot 0{,}9 = 1{,}809(t / shift)$

During pyrolysis process produced the following products:

- The liquid component of the fuel oil fraction (40%) – 0,724 $(t / shift)$
- High solids content (40%) - 0.724 $(t / shift)$
- Ferrous metals (8%) – 0,145 $(t / shift)$
- Pyrolysis gas (12%) – 0,217 $(t / shift)$

Working with the equipment using two pyrolysis furnaces simultaneously increases the capacity of the unit up to 6 t / day. It is doubled from previous calculation (3 t / day). There is no need in additional fuel, we save fuel resources, reduce emissions and there is no need to install gas tank for temporary storage of pyrolysis gas. When operating with Ecoenergetic plant setup, there may be some problems. Characteristics of faults and remedies are specified in (Table 9)

Table 9. Typical faults and troubleshooting

Name of the problem	Probable cause	Methods of correction
There is no required heat-ing retort	No power for the secondary gas	Check the position of the main taps
No cooling refrigerator	No water supply	To resume the supply of water
No blowing system	Fan does not work	1. Test presence supply of voltage 2.Test efficiency of fan 3. Replace the failed fan

5.4 The calculation of emissions from the installation Ecoenergetik

The composition and concentration of emissions of harmful substances in the exhaust flue was taken on the basis of natural measurements. It was made FSI "TsLATI in CFD" to install Ecoenergetic, designed for recycling of used tires with textile and metal cord, located in the Istra district of Moscow region.

$$M_i = 3600 \cdot 10^{-6} \cdot G_i \cdot t \cdot N_i$$

$G_i = 0{,}001 \cdot K_i \cdot Q$,

where

M_i - total emission of pollutant (i) (t/year)

G_i - maximum one-time emission of pollutant (i) (g / s)

t - time of work selected pollutant (i) (day/hour)

N_i - The number of working days of the source selection (i)-pollutant per year

K_i - Concentration of pollutant (i) (g/s)

Q - Consumption of gas-air mixture m ^{3} /s,

Sources of Pollution:

Harmful: sulfur oxides (calculated as SO2)

$G = 0{,}001 \cdot 125{,}4 \cdot 0{,}021 = 0{,}0026\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}0026 \cdot 24 \cdot 335 = 0{,}0752\ t/year$

Harmful: nitrogen dioxide

$G = 0{,}001 \cdot 207{,}1 \cdot 0{,}021 = 0{,}0043 g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}0043 \cdot 24 \cdot 335 = 0{,}1244\ t/year$

Harmful: carbon monoxide

$G = 0{,}001 \cdot 112{,}5 \cdot 0{,}021 = 0{,}0024\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}0024 \cdot 24 \cdot 335 = 0{,}0694\ t/year$

Harmful: carbon black

$G = 0{,}001 \cdot 11{,}6 \cdot 0{,}021 = 0{,}00024\ g/\sec$

$M = 3600 \cdot 10^{-6} \cdot 0{,}00024 \cdot 24 \cdot 335 = 0{,}0069\ t/year$

The results of the calculation in emissions (by source) Table 10

Harmful substance	Concentration of pollutant (g/s)	Consumption of gas-air mixture (m^3/s)	Time of work selected pollutant	The number of working days	Maximum one-time emission of pollutant (g / s)	Total emission of pollutant (t/year)
Sulfur oxides (calculated as SO2)	124,4	0,021	24	335	0,0026	0,0752
Nitrogen dioxide	207,1	0,021	24	335	0,0043	0,1244
Carbon monoxide (CO)	112,5	0,021	24	335	0,0024	0,0694
Carbon black (C)	11,6	0,021	24	335	0,00024	0,0069

The advantages of the upgraded installation are:

- Processing of any carbonaceous wastes
- Removable retort
- Indirect heating of raw materials
- Environmental security
- No need for cumbersome, slow and dangerous manual work
- Easily repairable equipment
- Work in all weather conditions, 24 hours a day, 365 days a year
- The high quality of the pyrolysis products
- Minimum environmental emissions

Due to all the above, the pyrolysis unit Ecoenergetic has a long life, the possibility of continuous operation and high productivity.

5.5 The calculation of operating costs

The calculation of operating costs is as follows:

$Z_c = Z_1 + Z_2 + Z_3 + Z_4 + Z_5$

Z_c - operating costs

Z_1 - salary(annual payroll for workers)

Z_2 - social contributions

Z_3 - material expenditures

Z_4 - amortization expenses

Z_5 - other expenses

1. Annual payroll for workers(Z_1)

$Z_1 = n \cdot C_1 \cdot T \cdot K_1 \cdot K_2,$

where

Z_1 - annual payroll for workers

n - number of employees that service equipment (2person)

C_1 - an average hourly rate of maintenance of equipment, (150rub)

T - annual fund operating time, T = 2680 hours

K_1 - coefficient of premiums and co-payments, K1 = 1.4

K_2 - coefficient taking into account the additional wages, K2 = 1.14

$Z_1 = 2 \cdot 150 \cdot 2680 \cdot 1{,}4 \cdot 1.14 = 1{,}283{,}148$ rubles (32000euro)

2. Social contributions(Z_2) (34% from Z_1)

Social contributions are equal to 34% from salary.

$Z_2 = 1{,}283{,}148 \cdot 0{,}34 = 436{,}270$ rubles (12000 euro)

3. Material expenditures (Z_3)

$Z_3 = R \cdot T \cdot K_1 \cdot K_2 \cdot K_3 \cdot C$,

where

R - installed capacity of energy consumption (kWh)

T - the annual number of hours of use of power load (hour)

K_3 -coefficient of demand, showing the degree of utilization of installed capacity, at maximum load (K_1 =0,3)

K_4 - coefficient of equipment load ($K_2 = 0{,}6$)

K_5 - coefficient of electricity shutdown ($K_3 = 0{,}95$)

C - cost of 1 kW power of electricity (3,68 rubles)

$Z_3 = 1{,}1 \cdot 8040 \cdot 0{,}3 \cdot 0.6 \cdot 0{,}95 \cdot 3{,}68 = 5{,}565$ rubles (140 euro)

4. Amortization expense (Z_4)

Amortization expense is equal to 15% of the original cost of the equipment.

$Z_4 = 2{,}772.000 \cdot 0{,}15 = 415{,}800$ rubles (11000 euro)

5. Repair costs (Z_5)

Repair cost is equal to 5% of the equipment cost.

$Z_5 = 2{,}772{,}000 \cdot 0{,}05 = 138{,}600$ rubles (4000 euro)

6. Current cost (Z_c)

Current costs are determined by the formula:

$Z_c = Z_1 + Z_2 + Z_3 + Z_4 + Z_5$

$Z_c = 1{,}283{,}148 + 436{,}270 + 5{,}565 + 415{,}800 + 138{,}600 = 2{,}279{,}383$ rubles (57000euro)

$Z_{(i)}$ Value	Cost 10^3 (rubles)	Cost 10^3 (euro)
Salary (Z_1)	1283	32
Social contributions (Z_2)	436	12
Material expenditures (Z_3)	5	0,14
Amortization expenses (Z_4)	415	11
Other expenses (Z_5)	138	4
Operating cost(Z_c)	2279	57

Table 11. Total calculation of economical data

5.6 Calculation of capital investments

To improve the environmental efficiency it was proposed to upgrade installation. It is proposed to figure out whether the introduction of a new waste recycling plant would be effective from both environmental and economical point of view.

Table 12. The data for the implementation of equipment Ecoenergetic

Name	**Capital investments rubles, (euro)**
Cost of equipment	2 520 000 (63 000 euro)
Transportation and installation of process equipment - 10% of its cost	252 000 (6 300 euro)
Total	2 772 000 (69 300 euro)

Capital equipment costs are calculated using the formula:

$Ktotal = K_1 + K_2$

where:

K_1 - the cost of equipment

K_2 - the cost of transportation and installation of equipment

$Ktotal$ = 2,520,000 + 252,000 = 2,772,000 rubles (63 000euro)

6 CONCLUSION

In this thesis, the main problems with tire recycling in Russia have been explained to the reader. A comparative analysis of different methods of tire recycling has been conducted in order to enable the reader to understand the pros and cons of each method separately. The analyzing all different tire recycling methods I came to pleasant conclusion that pyrolysis method is the most effective and efficient.

Disposal and recycling of tires in the world with extremely fast growing number of cars has gained great ecological and economic importance for all developing countries, including Russia. This is primarily due to the fact that used tires are source of a long-term contamination of the environment. Rubber is flammable and it is not a biodegradable material. Bunch of rubber tires is quite a convenient place to stay for whole colonies of rodents and insects, which are the source of infectious diseases. At the same time used tires are a source of valuable products (crumb rubber, carbon black, oil, etc.).

I examined the process of recycling tires by the process of pyrolysis in a specialized company. After analyzing the disposal of used tires used by the company, I found a number of shortcomings, the most important of which were significant emissions of pollutants into the atmosphere. The characteristics of the old recycling machine have been explained in detail and the modifications have been presented. The results shows that emissions have been minimized and productivity has increased. It should also be noted that improvement in the quality of pyrolysis products has also been achieved.

In the process I have made mutual suggestions to improve the environmental efficiency of the disposal of used tires by method of pyrolysis. Nevertheless, due to outdated technical solutions, the equipment and the used processes certainly have some technological challenges still to be solved in order to optimize the whole process, taking into account not only the end products but also keeping an eye on sustainable development. The work was carried out using technological and economic calculations.

As a result, we managed to minimize emissions from the equipment, increase productivity. It should also be noted that the improvement in the quality of the pyrolysis products was also achieved. Economic calculation shows that proposed the idea of replacing the equipment makes economic sense:

- Cleaning of the gas flow rate = 99%
- The payback period is 10 months.

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APPENDICES

Appendix 1. Manufacture and use of rubber crumb

The use of ground rubber in the form of fine rubber crumb is the most promising method of disposal of rubber waste and scrap tires. It allows maximizing storage facilities and utilizing elastic and mechanical properties of vulcanized rubber.

The most widespread technology in tire shredding incorporates moderate speed shredding while the rubber is at elastic stage, despite the much higher power consumption compared to the cryogenic technology.

According to this technology tire recycling is conducted in the following order: washing, cutting of wheel side ring, pre-crushing, coarse crushing, fine crushing, separation and grinding. Pre-crushing process is carried out by de-beading machine and shearing machine, and at later stages by crushing and grinding rollers, separator to remove metal particles and use of vibratory separator. .

Nowadays there are many different types of equipment for grinding rubber tires, having different performances in terms of capacity, design of working parts, etc. For this process plants use abrasive belts and discs, guillotines, disc blades, presses, mills, rotary knife mill and other equipment. In Russia traditionally applied equipment for crushing waste rubber is rolls. Abroad plants more often use disc and rotary shredders. However, the principle based on the use of rollers, is more efficient and less energy intensive.

The simplest technology of grinding waste rubber without metallic elements is shown in Figure 1.

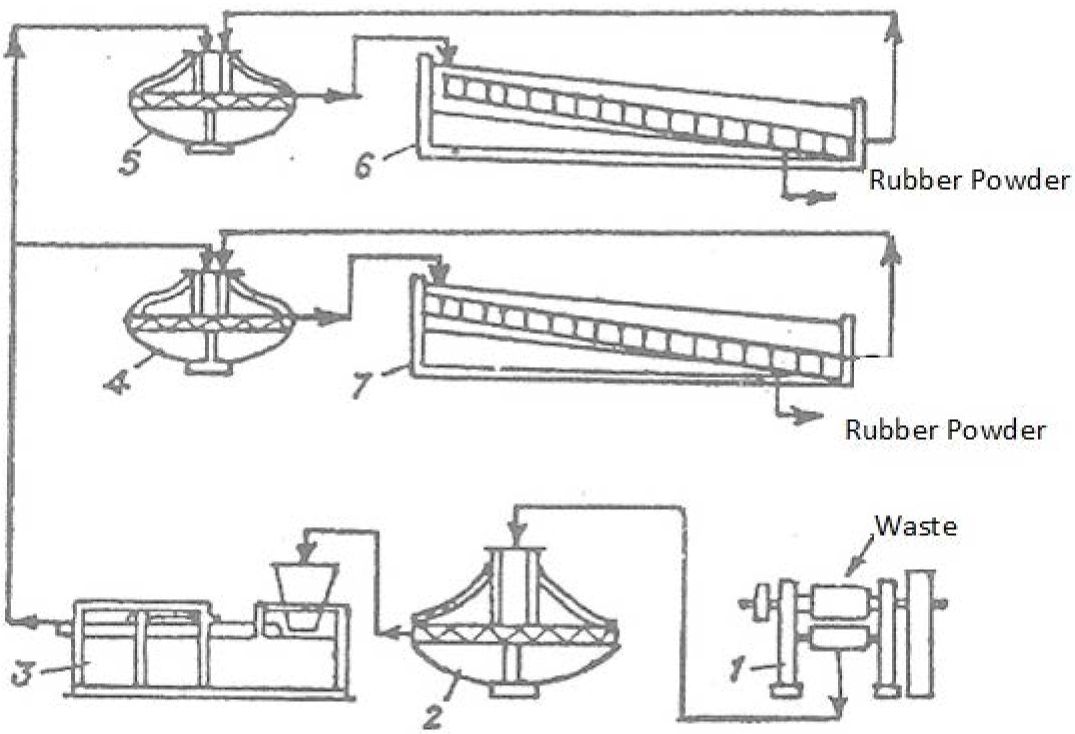

Figure 1. Technological scheme of grinding waste rubber (Source: Production instructions of industrial plant for recycling of used tires with method of pyrolysis. 2006. 28.)

1 - crushing roller 2 - coarse-grinding mill, 3 - magnetic separator, 4 and 5 - pulverizer, 6 and 7 - shaker. The performance of such a line is 300 - 350 kg of rubber flour / h with a particle size of 1 mm. More than half of the particles are less than 0.5 mm. Large rubber waste pieces are fed to the crushing rollers 1, followed by coarse grinding mill 2. Small waste (various rubber products) immediately comes to the mill 2. Crushed in a mill waste is sent back to the magnetic separator 3, and then with two streams goes to pulverizer 4 and 5, where it is crushed to 0.3 - 5 mm. The need to separate the flow after the mil caused a greater duration of grinding process of rubber particles to fine condition and returning dropouts after passing through the shredder waste transportation systems 6 and 7. Mesh size of the shaker is 1 mm, and particles that do not pass through, are returned to the regrinding in pulverizers.
Characteristics of the equipment used for the implementation of this technology are as follows (Table 1)

Table 1. Characteristics of the equipment

Crushing of waste	Crushing rollers (CR-800): a one-time download 15 -25 kg crushing to 5 minutes Gap between the rollers 1 - 1.5 mm temperature roll, "C: front 50 - 60 rear 60-70 Rotor diameter in mm: front 490 610 back Working length of rolls of 800 mm speed rolls, min: front 16.61

	rear 33.2 frictions 1:2,54 Electric motor power 110 kW
Screening of crushed waste	Shaker S 1145* 2445 : angle of sieve is 43 deg oscillation frequency of sieve is 200 min $^{-1}$ dimensions of 3,122 x1, 611x0, 857 m
Additional grinding	Disk mill D800, 10802-RZ: productivity of 200 kg / h speed of rotation 533 min
Sift of the crumbs	Shaker M 1485x1215: Angle of 6 degrees The oscillation frequency of 365 min Screen size 2,135 x0, 700x0, 550 m

(Source: Production instructions of industrial plant for recycling of used tires with method of pyrolysis. 2006. 18.)

Tires with metal cord on this technology cannot be milled. For this purpose a different more powerful machinery is used, providing a preliminary cutting-out of the tire bead and cutting tires into pieces. For shredding tires plants use more powerful model rolls Cr-800 710/710 capacity 3500 kg / h with a capacity of 353 kW electric motor. Dimensions of rollers are 6695x4469x1880 mm and weight 50.6 tons. (Production instructions of industrial plant for recycling of used tires with method of pyrolysis. 2006. 18.)

In particular, it is known that the destruction of polymers in the glassy or rubbery state (but with high speed) occurs with very little power.

Appendix 2. Cryogenic grinding process

With cryogenic grinding process tires cooling for 25 minutes in drum-type devices, the consumption of liquid nitrogen is 0.25 - 1.2 kg per 1 kg of the crushed material. Chilled shredded tire in different types of crushers (Fig. 1). The most effective use of equipment is shown in Figure 5. Primary cryogenic grinding is performed by a hammer, cord separator and final .The resulting fragmentation of chips in size is from 0.15 to 20 mm. The cost of liquid nitrogen is 2/3 of the total cost of operation of the plant. (Production instructions of industrial plant for recycling of used tires with cryogenic method. 2009. p 20)

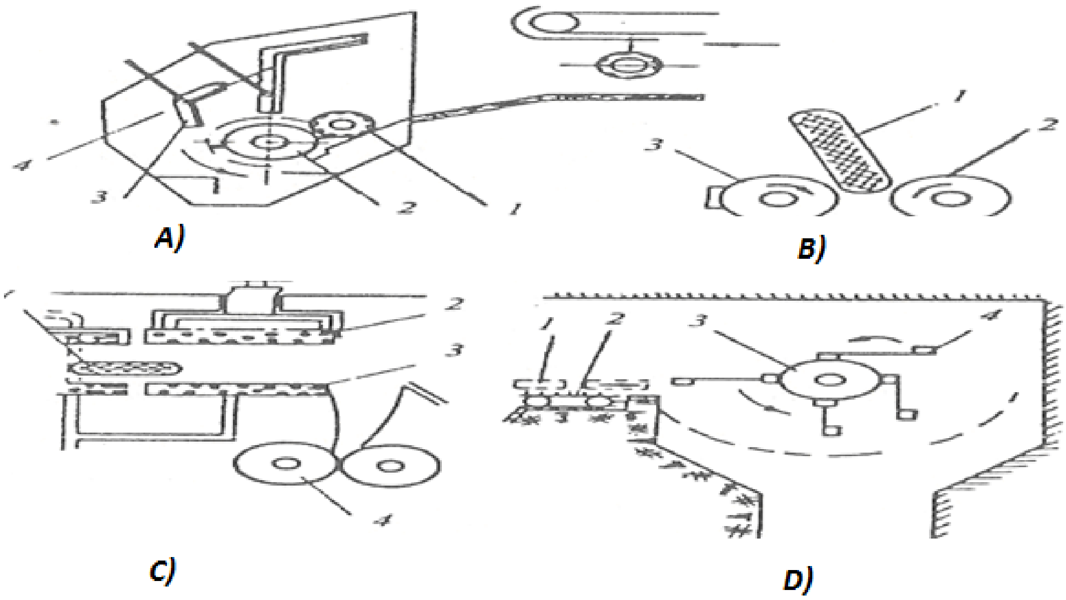

Figure 1. Mechanisms for cryogenic grinding tires with metal cord (Source: Production instructions of industrial plant for recycling of used tires with cryogenic method. 2009. p 20)

a)-impact crusher (1 - tire 2 - cylinder, 3.4 - Deflector), b)-roll crusher (1 - tire, 2.3 - mobile and stationary rolls), c)-hammer (1 - tire; 2.3 - insulated matrix, punch, 4 - crusher), d) hammer crusher (1 - tire 2 - transporter 3 - rotor, 4 - hammer)

Process scheme of cryogenic grinding is shown in Figure 2.

In preparation for cryogenic grinding tires are washed, sorted and sent to de-beading machine 1 to remove bead. Neatly, tire goes into a cooling chamber 2, where liquid nitrogen is applied. Drum type drying oven can be used after some modifications as cooling equipment. Tires are cooled down to -120 ° C (temperature of all rubber types is practically by -70 C).

Existing stock of tires is required for cooling the heat leakage and compensating during the move from the cooling chamber to the hammer 3, to compensate for heat release at impact hammer due to conversion of kinetic energy into thermal. Hammer has shaped core and cavity, which is breaking the frozen tires. Impact energy is 38 kJ, the punch stroke is 700 mm, and the punch weight is 800 kg. Shredded tire after the hammer are sent back to the pulley iron separator 4, where separation of rubber from textile and metal takes place. Rubber crumb goes to separation. Fractionation and regrinding is done on standard crushing and grinding mill.

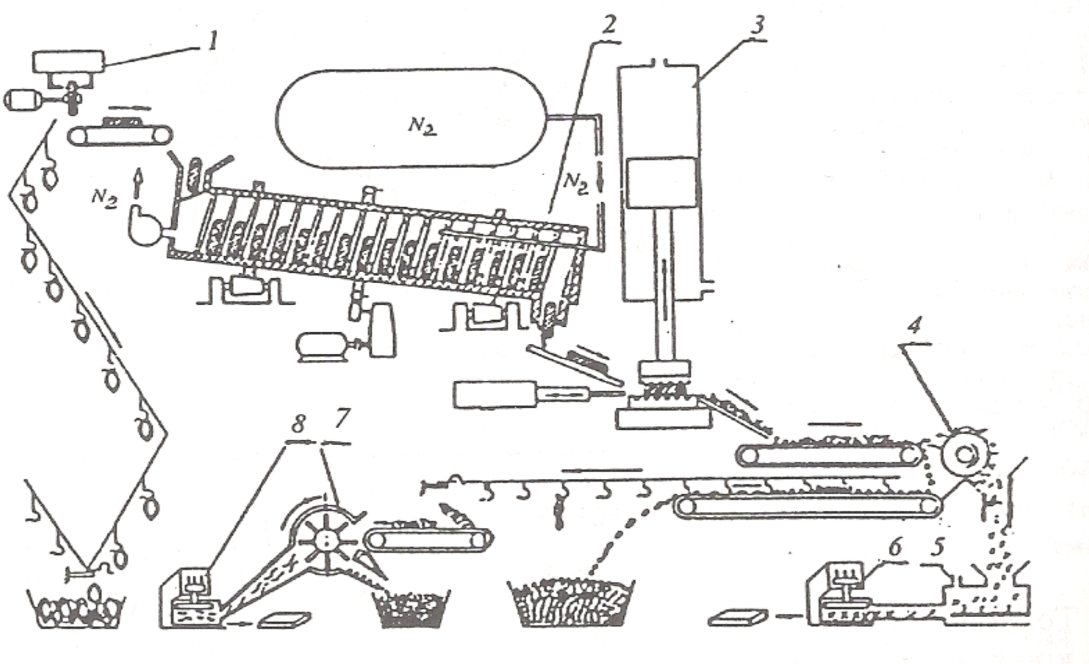

Fig.2. Cryogenic crushing of used tires (Source: Production instructions of industrial plant for recycling of used tires with cryogenic method. 2009. p 38)

1 - debeading machine 2 - cooling chamber 3 - Hammer 4 - sheave iron separator, 5 - kiln, 6 and 8 - baler, 7 - rotary cutter.

Steel cord is fed into the kiln 5 for burning rubber residue which is on wire and then it goes to baler 6, textile cord goes to regrinding in a rotary cutter 7 and finally it goes to baling press 8. As a result of the cryogenic fracturing rubber is transformed to a small fraction, which contains up to 75% of rubber, with 57% of the chips of size 1.25 - 20 mm and 24% - from 0.14 to 1.25 mm. This can significantly reduce the cost of re-grinding of rubber crumb with conventional methods. The specific energy consumption for the fracturing of the tires in the vitrifactioned form is 1.8 times less than by fracturing in elastic condition.

In recent years, the technology industry has developed high shear milling (compression-shift) by different methods by Russian scientists. The basis of the method is a complex physico-chemical process of multiple fractures of solids under intense compression of complex loads with a shift. Under certain temperature and pressure tires quickly disintegrates into fine particles. The advantages of this technology are the relatively low power consumption and ability to get out of fine particles of waste rubber with highly developed surface. To implement this method of grinding waste rubber the specialists have designed continuous rotary shredders.

Shredding rotor disperser is shown in Figure 3.

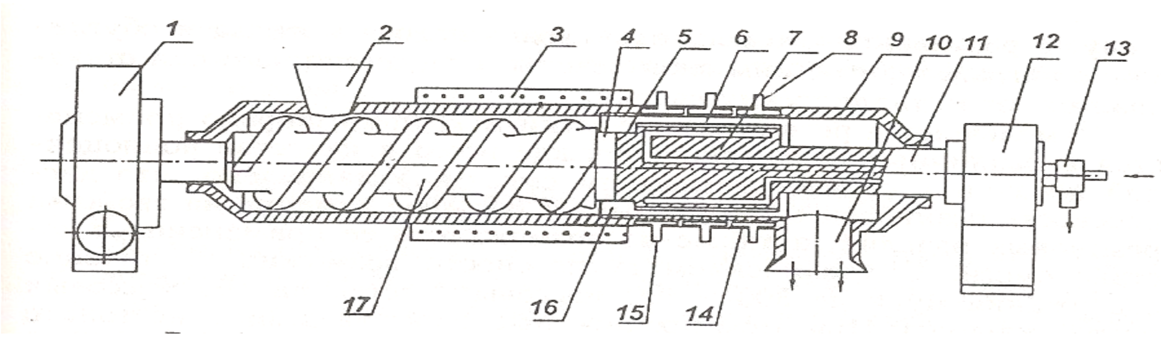

Fig.3. Shredding rotor assembly rubber dispersant (Source: Production instructions of industrial plant for recycling of used tires with cryogenic method. 2009. p 44)

1 - driving mechanism 2 - feed hopper 3 - heater, 4 and 5 - ring groove 6 - annular gap 7 - rotor, 8 - fitting (water outlet) 9 - body structure, 10-socket, 11 - worm shaft-rotor, 12 - thrust bearing, 13 - unit, 14 - flow Chambers, 15 - fitting (supply of cooling water), 16 - annular, 17 auger

Shredder works as follows:

Tire fraction (size 30x40x10 mm, including steel cord) comes through the feed hopper 2 in the chamber formed by the housing 9, 17 and a screw rotor 7. In order to start the process, the units with moderated capacity have incorporated heater 3. Auger and impeller have a single driving mechanism 1. On the opposite side of the screw shaft 11, the rotor rotates in the support bearing 12. Lateral surface of the sealing screw has spiral grooves, the depth of which decreases in the direction from the drive to the rotor. At the end of the screw rotor there is an annular groove 4 and similar groove on the outer cylindrical surface of the rotor 5. Both grooves form an annular chamber 16, in which the rubber waste is compressed with a shift. Material is heated for a few seconds from 70 to 140 ° C. To cool the body of dispersant we need three flow-through chambers 14, cooling water feeds through the sleeve 15, and water flows out through fitting 8. The rotor shaft is also cooled by water that enters and leaves it with the assembly 13. Unloading shredded rubber waste produced through the opening socket 10, which is done on the annular gap 6, formed by the outer surface of the rotor and the inner surface of the housing.

Rotary grinder produces rubber powder, practically uniform particle size (10-50 microns). Such a particle size and a very large specific surface area (0.5 -5 m / g) makes rubber powder with completely new properties. It can be administered in the polymer composition in large quantities without degradation of it properties.

One interesting way of separation of rubber from steel cord after shredding tires was developed by Japanese engineers. Products are subjected to high-frequency grinding with heat, which results in the heating of metal and charred border layer of rubber with it, causing it to peel away from the metal particles.

Shredded rubber in the form of flour and breadcrumbs are widely used in various fields, especially as a complete supplement for fresh rubber compounds. The dispersion of rubber flour has a great impact on the properties of rubber products, as well as the possibility of its application in the mixture. It is advisable to use crumb rubber in asphalt concrete pavements. Due to the increased friction properties and better wear resistance, such coatings can be effective on the mountain roads, squares and streets with heavy traffic, and also for bridges and tunnels.

High elastic properties imparted by rubber fraction, make the material very useful for creating roads in the regions with large temperature differences, for the construction of tramways (vibration protection properties), treadmills and stadiums. In the manufacture of asphalt pavement rubber pellets up to 25 mm can be used without removing particles of steel and fiber. The composition is made in a concrete mixer or heated mixer (asphalt mixture). Crumb rubber is used in anti-corrosion coatings for bituminous underbody protection, waterproofing layers and oil protection of soil, surface water treatment of spilled oil, and for other purposes.