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" IGOR SIKORSKY KYIV POLYTECHNIC INSTITUTE"
INSTITUTE OF ENERGY SAVING AND ENERGY MANAGEMENT
DEPARTMENT OF AUTOMATION OF ELECTRICAL AND
MECHATRONICAL COMPLEXES**

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Admitted to the defense

Head of the department

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« ____ » _____ 2024.

MASTER THESIS

for a master's degree

**by specialty 141 "Electric power engineering, electrical engineering and
electromechanics"**

educational program (specialization) "Engineering of intellectual electrical
engineering and mechatronic complexes"

**by the topic: « Electromechanical equipment and an automated system for
sorting used tires and their pyrolytic disposal»**

Performed by: student of the 2nd year study, group ΓA-31mmi:

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I certify that in this master's thesis there are no
borrowings from the works of other authors
without appropriate references.

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Kyiv – 2024

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« ____ » _____ 2024

TASK
for a student's master's thesis to
Yang Bozhi

1. Dissertation topic " Electromechanical equipment and an automated system for sorting used tires and their pyrolytic disposal ", scientific supervisor of the dissertation Sergii Boichenko,

Doctor of Technical Sciences, Professor. approved by order of the university dated " 12 " 11 , 2024 year HAKA3 № 141/24-ci .

2. The deadline for the student to submit a dissertation

3. Investigation object: Focuses on an automated system to sort used tires efficiently, facilitating their eco-friendly pyrolytic disposal for energy and material recovery.

4. Input data: Input data includes tire dimensions, material composition, wear level, sorting criteria, pyrolysis parameters, and system automation requirements.

5. The list of tasks to be developed: Processing special literature on technologies for sorting of used (old) tires. Processing special literature on technologies for pyrolysis disposal of used (old) tires. Formulation of the goal, object, subject and tasks of thesis. Construction of a general methodological scheme (algorithm block diagram) for the performance of qualification work.

6. Oriented list of graphic (illustrative) material: presentation

7. Consultants of Master thesis chapters

Section	Name, Family Name and Position of Consultant	Signature	
		Task issued	Task accepted

8. Date of issue the task _____

Calendar plan

Календарний план / Schedule

	Task	Term implementation	Status of execution
1	Processing special literature on technologies for sorting of used (old) tires	01.06-21.10.2024 p.	
2	processing special literature on technologies for pyrolysis disposal of used (old) tires	01.06-21.10.2024 p.	
3	Formulation of the goal, object, subject and tasks of thesis. Construction of a general methodological scheme (algorithm block diagram) for the performance of qualification work	01.06-21.10.2024 p.	
4	Electromechanical equipment and an automated system for sorting of used (old) tires	Up to 28.10.2024 p.	
5	Electromechanical equipment and an automated system for pyrolysis disposal of used (old) tires (mnemonic diagram)	Up to 04.11.2024 p.	
6	Characteristics of system for sorting of of used (old) tires and their pyrolysis disposal (dimensions, technological parameters, automation level)	Up to 04.11.2024 p.	
7	Developing a startup project of system for used (old) tires and their pyrolysis disposal	Up to 11.11.2024 p.	
8	Participation in the conference	27.11.2024	
9	Preparation for the previous one protectionRepresentation work at the department	04.12.2024 p.	
10	Accounting comments, recommendations and defense preparation	Up to 13.12.2024 p.	
11	DEFENSE of master's thesis	23.12.2024 p.	

Issue date of the task « » 2024 .

Thesis supervisor

Sergii Boichenko

(supervisor's signature)

The task was accepted by

Bozhi Yang

(signature of the graduate)

Анотація

Утилізація використаних шин створює значні екологічні виклики, що зумовлює необхідність пошуку інноваційних рішень для управління та переробки цього стійкого потоку відходів. У цьому огляді розглянуто розробку та застосування електромеханічного обладнання й автоматизованих систем для сортування використаних шин та їх подальшої піролізної утилізації. У статті підкреслюються досягнення у технологіях сортування шин, включаючи інтеграцію датчиків, машинного зору та штучного інтелекту для точного визначення та категоризації за властивостями матеріалу й розмірами.

Піроліз, термохімічний процес, який розкладає шини на вторинні продукти, такі як піролізна олива, технічний вуглець і металобрухт, розглядається як стійкий метод переробки. Критично аналізується роль електромеханічних систем у оптимізації підготовки сировини, енергоефективності та контролю викидів під час піролізу. Основна увага приділяється масштабованості цих систем, їх економічній доцільності та відповідності екологічним нормам.

Огляд наявних установок та пілотних проєктів дозволяє оцінити їхню реальну ефективність, виклики та можливості для інновацій. У статті вказуються прогалини в сучасних технологіях, пропонуються напрями для досліджень з метою вдосконалення інтеграції систем, а також обговорюються ширші наслідки цих досягнень для забезпечення стійкого управління відходами та сприяння циркулярній економіці у сфері переробки шин.

Ключові слова: електрогенератор, діагностика, комп'ютерне моделювання, стартер, енергоефективність

Abstract

The disposal of used tires poses significant environmental challenges, driving the need for innovative solutions to manage and recycle this persistent waste stream. This review explores the development and application of electromechanical equipment and automated systems for sorting used tires and their subsequent pyrolytic disposal. The article highlights advancements in tire sorting technologies, including the integration of sensors, machine vision, and artificial intelligence for accurate identification and categorization based on material properties and dimensions.

Pyrolysis, a thermochemical process that decomposes tires into reusable byproducts such as pyrolytic oil, carbon black, and scrap steel, is examined as a sustainable recycling method. The role of electromechanical systems in optimizing feedstock preparation, energy efficiency, and emissions control during pyrolysis is critically analyzed. Emphasis is placed on the scalability of these systems, their economic feasibility, and compliance with environmental regulations.

Case studies of existing installations and pilot projects are reviewed to assess real-world performance, challenges, and opportunities for innovation. The article concludes by identifying gaps in current technologies, proposing research directions for improving system integration, and discussing the broader implications of these advancements for achieving sustainable waste management and promoting a circular economy in tire recycling industries.

Keywords: Used tire disposal, Pyrolysis, Electromechanical systems, Automated sorting, Sustainable recycling.

CONVENTIONAL ABBREVIATIONS

GTR- ground tire rubber
PLC - Programmable Logic Controller
SLC - Structured Control Language
ROI - Return on Investment

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INTRODUCTION

In recent years, one of the major environmental issues worldwide has been the final disposal of solid waste. Among all types of solid waste, the number of used tyres has been increasing at a faster rate due to the rising demand for vehicles, making used tyres a primary concern. Due to their specific physical and chemical properties, used tyres are difficult to degrade under natural conditions, making them unsuitable for landfill disposal[1]. Common recycling methods for used tyres include retreading, material recovery, energy recovery, and pyrolysis[2,3].

Pyrolysis, as one of the methods for processing used tyres, can produce useful products such as pyrolysis gas, pyrolysis oil, pyrolytic carbon, and steel wire[4-6]. Therefore, it is considered one of the most promising methods for comprehensive processing of used tyres. The pyrolysis gas has a high calorific value, and the energy generated from burning the gas can not only meet the energy needs of the pyrolysis process itself but also be utilised for other applications. Pyrolysis oil from used tyres is a dark brown/black, medium-viscosity liquid with a sulphur/aromatic odour. Through desulphurisation, the sulphur content in pyrolysis oil can be reduced, enabling its use in the production of petrol and diesel[7,8]. Pyrolytic carbon can be processed into activated carbon through an activation process, making it useful as an adsorbent[9].

However, traditional pyrolysis methods suffer from drawbacks such as low efficiency, high energy consumption, high pollution levels, and the production of mixed, low-value outputs[3,10]. Thus, the use of electromechanical equipment and automated systems to assist in the sorting and pyrolysis of used tyres holds significant practical and economic value.

Investigation actuality. The relevance of this study lies in the need to ensure reliable power supply from autonomous power units with internal combustion engines, which are used in critical sectors such as industry and transportation. The reliability of such systems depends on timely diagnostics and detection of wear in key components, particularly the cylinder-piston group, which is the main cause of their malfunctions.

Traditional diagnostic methods are labor-intensive and can be inaccurate. With the development of new engine models, there is a demand for innovative diagnostic approaches. The study proposes a modernized diagnostic method based on starter current analysis, which increases accuracy and reduces maintenance costs, making it effective for use in both modern and new engine models.

The goal of the work. The investigation into electromechanical equipment and automated systems for sorting and pyrolytically disposing of used tires is focused on developing highly efficient and environmentally friendly recycling processes. Tire recycling is a critical issue due to the vast accumulation of waste tires globally, which poses environmental challenges. Automated systems are designed to streamline this process by sorting, shredding, and processing tires with minimal manual intervention, thus improving productivity and reducing labor costs.

Object of investigation..

Subject of investigation.

The scientific novelty

Practical results.

Publications 2024

Approbation of work.

CHAPTER 1. PROCESSING ON TECHNOLOGIES FOR SORTING OF USED (OLD) TIRES

1.1 Current status and hazards of waste tires:

Currently, the automotive and transportation industries are developing rapidly. It is forecasted that the global annual production of automobiles will reach 110 million units by 2025 [11]. As a by-product of vehicle usage, the output of waste rubber tyres is also showing an upward trend year by year.



Figure 1.1 The tire life cycle.

Waste car tyres pose significant environmental pollution and damage[12,13], including:

Landfill Space: Discarded tyres take up a large amount of space in landfills due to

their size and non-biodegradable nature. They can take hundreds of years to decompose, leading to long-term occupation of land resources.

Fire Risk: Waste tyres are flammable, and tyre fires are difficult to extinguish. They release toxic gases and dense smoke when burned, which can severely pollute the air and pose health risks to nearby communities.

Water Contamination: Tyres can leach harmful chemicals, such as heavy metals and plasticizers, into the soil and groundwater over time. This can contaminate water supplies and affect plant and animal life.

Breeding Ground for Pests: Accumulated tyres can collect rainwater, creating stagnant pools that become breeding grounds for mosquitoes and other pests, contributing to the spread of diseases.

Microplastic Pollution: As tyres wear down on the road, they release microplastics that eventually enter waterways and oceans, contributing to the global problem of microplastic pollution, which threatens marine ecosystems and food chains.

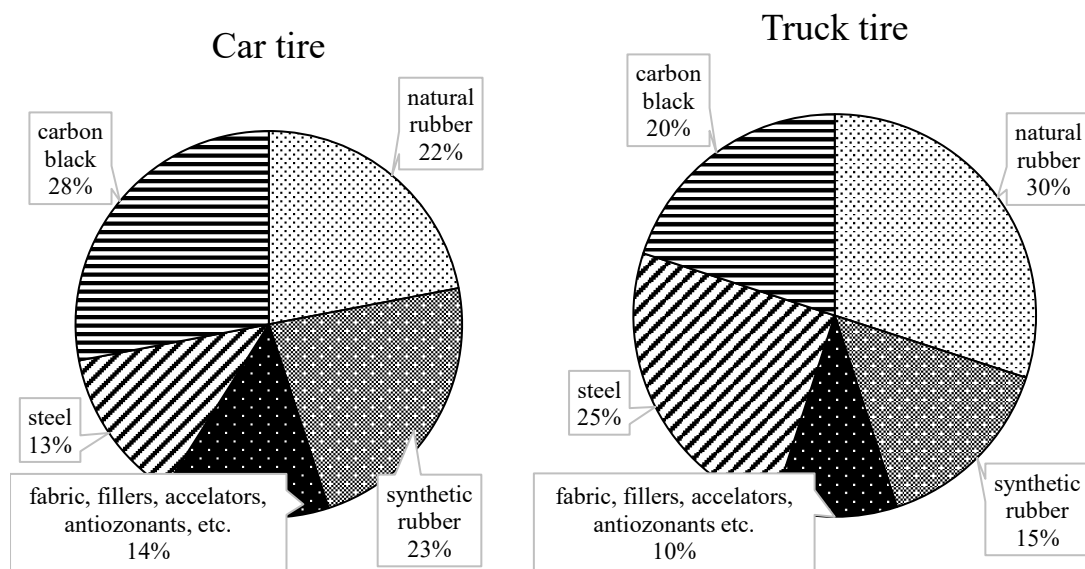


Figure 1.2- Composition of tires [10]

1.2 Classification and composition of waste tires:

The main components of waste tyres, which vary depending on the type, typically include natural and synthetic rubber, fillers (such as carbon black, silica, and chalk or

carbon), reinforcing materials (metals and textiles), plasticisers (oils and resins), vulcanising agents (sulphur and zinc oxide), and additives[14]. The variation in tyre composition is a key factor affecting tyre performance, with over 100 different compounds potentially being added during the manufacturing process depending on the intended application [15]. Rubber materials are the primary component of tyres, existing in the form of C_xH_y [16]. Along with fibrous materials, they belong to the category of thermosetting polymers.

Table.1-1 Typical composition of passenger car and truck tires[17]

Composition	Rubber	carbon black	Metal	Textile	Zinc Oxide	Sulfur	Additives
Passenger car tires /wt%	47	21.5	16.5	5.5	1	1	7.5
Truck tires /wt%	45	22	21.5	0	2	1	5

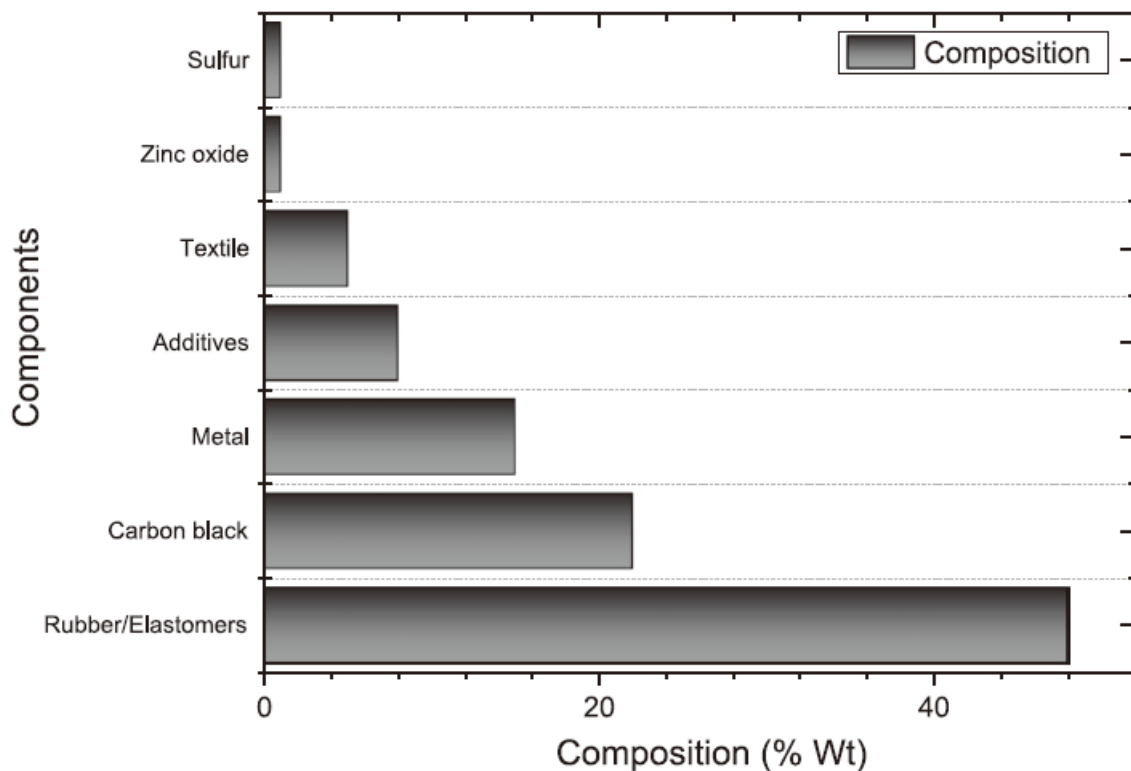


Figure 1.3- The average composition of tires [17]

The main rubber components in tyres are[18,19]:

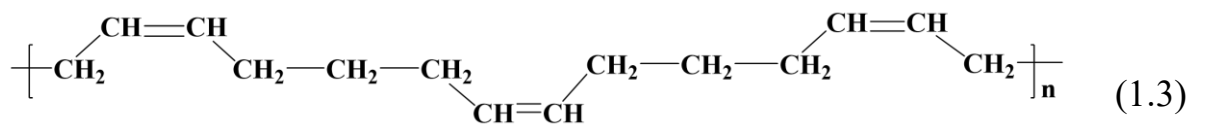
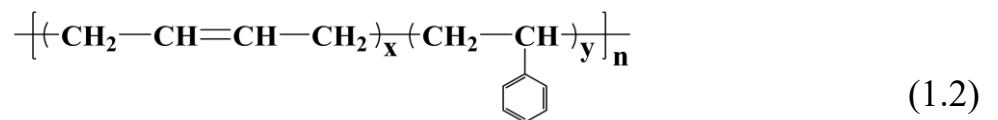
Natural Rubber(NR): Provides elasticity and flexibility.

Styrene-Butadiene Rubber (SBR): A synthetic rubber that enhances durability and resistance to wear.

Polybutadiene Rubber (BR): Improves wear resistance and contributes to the tyre's low rolling resistance.

Butyl Rubber: Often used in the inner lining of tyres due to its low air permeability, helping to maintain tyre pressure.

The chemical structures of various types of rubber are as follows: Formula 1.1 is NR, Formula 1.2 is SBR, Formula 1.3 is BR.



1.3 Waste tire classification technology and research status

The classification of waste tyres is essential for their effective recycling and reuse, as different types of tyres require different treatment processes. The research into waste tyre classification and related technologies has progressed significantly, covering several key aspects:

1.3.1. Manual Sorting and Visual Inspection

Manual Sorting: This is the traditional method where tyres are sorted by size, type, and condition manually. It is simple but labour-intensive and time-consuming.

Visual Inspection: In some cases, visual inspection methods are used to assess the condition of tyres to determine if they can be reused or need to be recycled. While effective, this method lacks precision and consistency.

1.3.2. Automated Classification Techniques

Computer Vision Systems: Recent advances use computer vision and machine learning algorithms to identify tyre types, sizes, and wear conditions. Cameras and sensors capture images of tyres, and algorithms classify them based on predefined characteristics. This method increases efficiency and accuracy compared to manual sorting.

X-ray and Infrared Scanning: These technologies allow for non-destructive analysis of tyre composition and structure, helping to distinguish between different types of rubber, steel content, and internal wear patterns. This is particularly useful for assessing the potential for reuse or recycling.

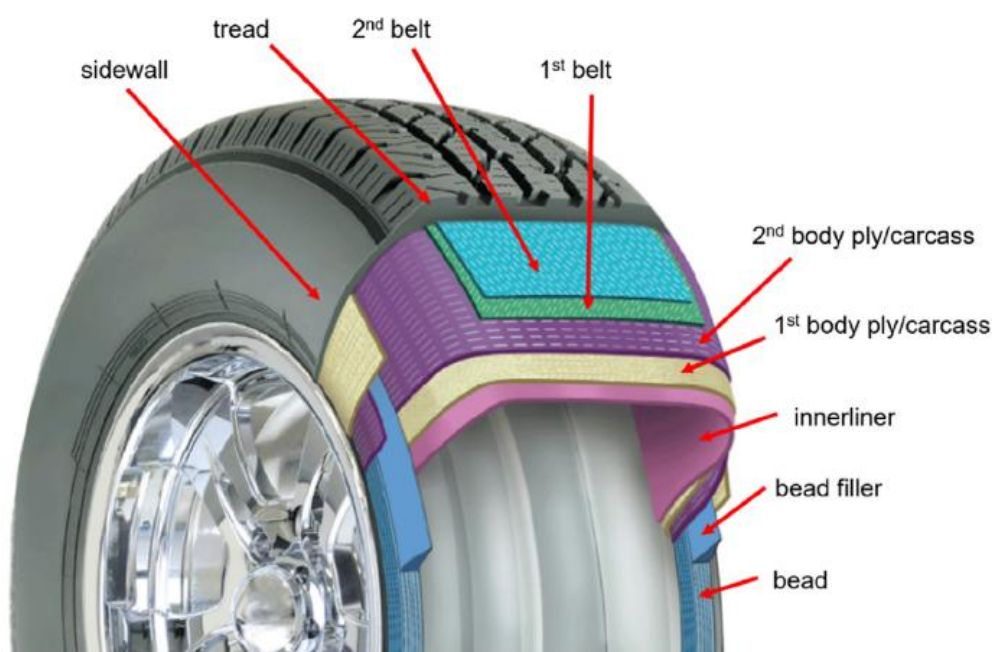


Figure 1.4 Components of a tire [20]

1.3.3. Chemical Analysis

Spectroscopy: Techniques such as Fourier-Transform Infrared (FTIR) spectroscopy and Raman spectroscopy are used to analyse the chemical composition of tyre materials. This helps to classify tyres based on the proportion of natural vs. synthetic rubber and other fillers, providing a detailed breakdown of their components.

Thermogravimetric Analysis (TGA): TGA is used to understand the thermal

stability of different rubber components in tyres. By heating the rubber, the process measures weight changes, which helps identify specific rubber types and their suitability for certain recycling methods.

1.4 Pretreatment of waste tires before disposal

Before waste tyres can be disposed of or recycled, they must undergo several pretreatment processes to improve handling, efficiency, and environmental safety during disposal. These pretreatment steps ensure the tyres are appropriately processed to maximise recovery, minimise environmental impact, and prepare them for specific recycling or disposal methods. It includes Shredding, Steel Removal, De-beading, Washing and Cleaning, Granulation and Grinding, Cryogenic Freezing, Pyrolysis Feedstock Preparation.

Shredding: Waste tyres are cut into smaller pieces using shredders. The shredding process reduces the size of the tyres, making them easier to handle, transport, and process. Tyre shredding typically happens in multiple stages, including primary shredding (into larger chunks) and secondary shredding (into finer pieces or rubber chips).

Steel Removal: Tyres contain steel belts that provide structural reinforcement. Magnetic separation or mechanical processes are used to extract steel from shredded tyres.

De-beading: Tyre de-beading involves removing the steel wire from the tyre's bead (the inner edge of the tyre that sits on the wheel rim). This is done using specialised de-beading machines.

Washing and Cleaning: Tyres can accumulate dirt, oils, and other contaminants over time. In some cases, pretreatment includes washing tyres to remove these contaminants.

Granulation and Grinding: After shredding, tyres can be further ground into finer particles through granulation and grinding processes. Granulation involves cutting the tyre into even smaller pieces, while grinding reduces the rubber to fine powders or

crumb rubber.

Cryogenic Freezing: Cryogenic freezing involves cooling tyres to extremely low temperatures using liquid nitrogen. This makes the rubber brittle and easier to break into smaller pieces.

Pyrolysis Feedstock Preparation: In preparation for pyrolysis, where tyres are decomposed at high temperatures without oxygen, tyres must be shredded into small pieces for more efficient processing.

CHAPTER 2. PROCESSING PYROLYSIS DISPOSAL OF USED (OLD) TIRES

Currently, there are several main methods for the treatment and reuse of waste tyres[21]:

Direct Use and Original Modification: Direct use primarily involves utilising the resilience of tyres in applications requiring shock absorption. Original modification refers to simple physical processing of waste tyres, such as perforation for easier fixing or cutting to adapt to different shapes. These two methods make relatively thorough use of waste tyre resources and are environmentally friendly, but their application range is quite narrow, accounting for only about 1% of all waste tyre utilisation methods [4].

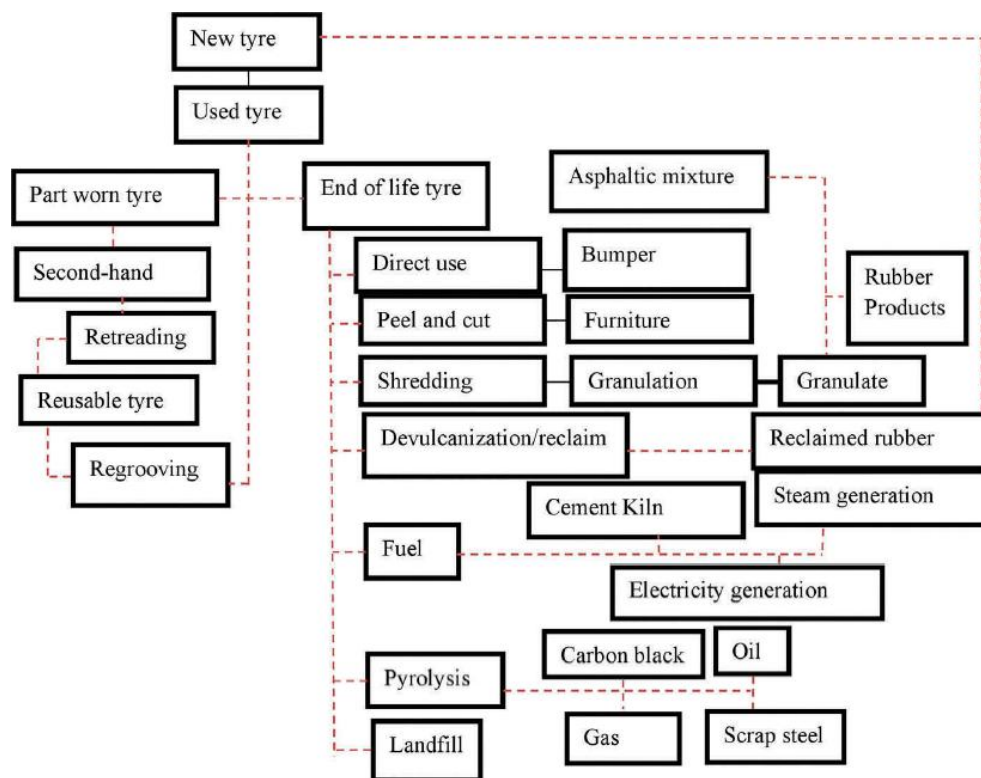


Figure 2.1- Waste tire management options [21]

Retreading: Retreading refers to the process of reconditioning discarded tyres to make them reusable. This method involves targeted processing of the tyres, resulting in lower costs, with the selling price of retreaded tyres being only 15% to 30% of new tyres. Although the price of retreaded tyres is low, their performance does not significantly diminish; they can achieve a safe driving mileage of 75% to 100% of

that of new tyres, making them economically advantageous [5]. However, due to the nascent state of waste tyre issues in our country, the relevant policies are not sufficiently developed, and retreading technology has not been adequately refined, resulting in the insufficient development of the retreading industry.

Recycled Rubber and Rubber Powder: Waste tyres contain a significant amount of rubber, which can be processed through devulcanisation to obtain recycled rubber. This recycled rubber can substitute natural rubber in certain applications, conserving natural resources and reducing production costs. However, the high sulphur content in waste tyres can lead to serious environmental issues during the production of recycled rubber. As a result, a more feasible approach is to undergo simple physical processing of waste tyres to produce rubber powder, which involves only shape changes and is more environmentally friendly.

Incineration: The heating value of waste tyres is approximately 29-37 MJ/kg, comparable to that of high-quality coal, making them a potential alternative fuel. The heating value of waste tyres is 69% higher than that of wood, 4% higher than that of coke, and 10% higher than that of bituminous coal [6]. However, simple incineration utilises only the calorific value of the tyres and does not fully leverage the rich additives contained within them.

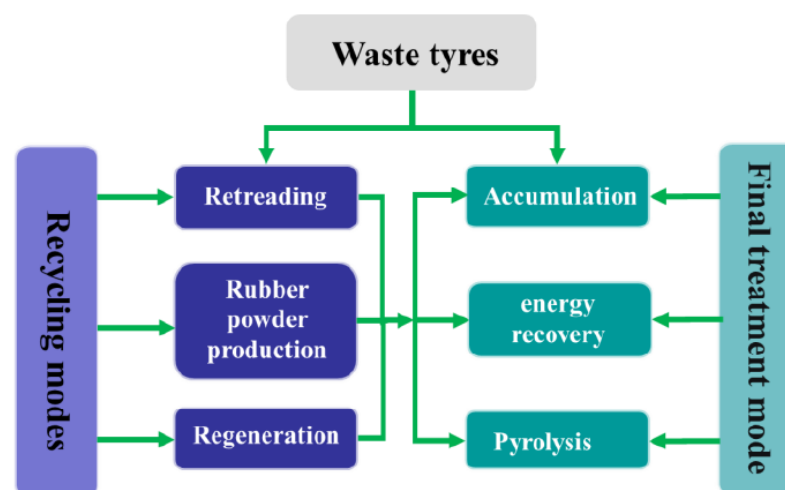


Figure 2.2 Main methods of WasteTyres treatment.

High-Temperature Pyrolysis[22]: Pyrolysis refers to the process of heating

materials in the absence of oxygen or an inert atmosphere, decomposing the organic substances in the materials into volatile oils and gases, with the remaining solid being carbon black. Compared to original modification and the production of recycled rubber, pyrolysis achieves a comprehensive utilisation of waste tyres. This process can break down tyres into solid, liquid, and gas phases, and through further processing, it yields higher-value products while also allowing for the recovery of the steel wires contained in the tyres, thereby facilitating the resource utilisation of waste tyres.

2.1 Pyrolysis types and products:

As the rubber that constitutes tyres is primarily made up of long-chain hydrocarbons[Formula 1.1,1.2,1.3], pyrolysing tyres to obtain these valuable hydrocarbons represents a more rational and economical approach. Recovering valuable hydrocarbons from waste tyres for use as energy and chemical feedstocks will reduce reliance on fossil fuels, thereby helping to mitigate the threats posed by diminishing fossil fuel reserves and climate change.

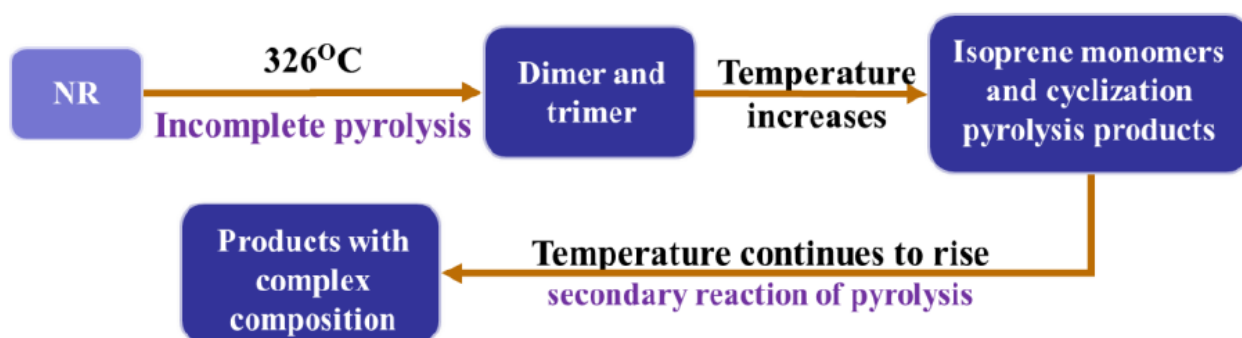


Figure 2.3 The pyrolysis process of NR[2]

Pyrolysis involves the thermal decomposition of the carbonaceous volatile fraction of the sample (in this case, the rubber polymers) using gases such as nitrogen, argon, or helium in an inert atmosphere, to produce hydrocarbon-rich syngas, oil, and carbon black. The pyrolysis process can yield the following products: a gaseous fraction composed of hydrogen, methane, ethylene, ethane, carbon oxides, and other combustible gases; a liquid fraction consisting of tar, water, and various organic substances (oils); and a solid fraction made up of residual carbon, ash, aggregates, and

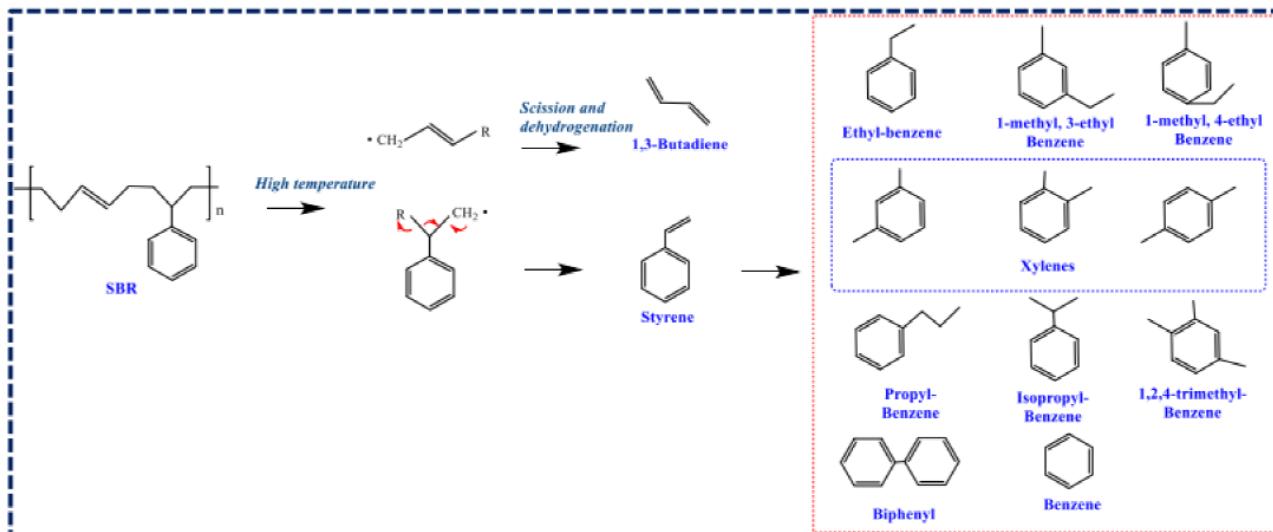


Figure 2.5 The pyrolysis process of SBR[2]

Although the concept of pyrolysing waste may seem straightforward, the products are often complex mixtures of hydrocarbons with a wide compositional range, extending from light aliphatic gases to coke. Therefore, depending on the ultimate objectives of the pyrolysis, it is necessary to identify optimal conditions for the type of feedstock and the process characteristics (such as particle size, temperature, reaction time, catalysts, heating rate, type of atmosphere, and its flow rate).

2.2 Pyrolysis products:

There are many types of pyrolysis, each with different operational conditions. The three most important conditions include heating rate, residence time, and reaction temperature. Based on residence time, pyrolysis can be simply classified into slow pyrolysis and fast pyrolysis. Fast pyrolysis, sometimes referred to as flash pyrolysis, implies a higher heating rate and shorter vapour residence time compared to slow pyrolysis. Pyrolysis can also be classified based on the environment used, such as oxidative pyrolysis, hydrogenative pyrolysis, steam pyrolysis, catalytic pyrolysis, and vacuum pyrolysis. Furthermore, it can be categorised by the heating systems employed, including microwave and plasma pyrolysis. Generally, different types of pyrolysis correspond to different structural forms of pyrolysis reactors, such as fluidised bed and entrained flow reactors, which are associated with fast pyrolysis,

while fixed bed reactors are linked to slow pyrolysis (batch or semi-batch processes). Of course, fast pyrolysis can also be conducted in fixed bed reactors by adjusting the heating rate and the residence time of the volatiles. For other types of reactors, such as spiral and rotary cone reactors, the high heating rates and relatively short residence times are typically used for the production of pyrolysis oils, and these can also be classified as fast pyrolysis. Below are descriptions of several common types of pyrolysis.

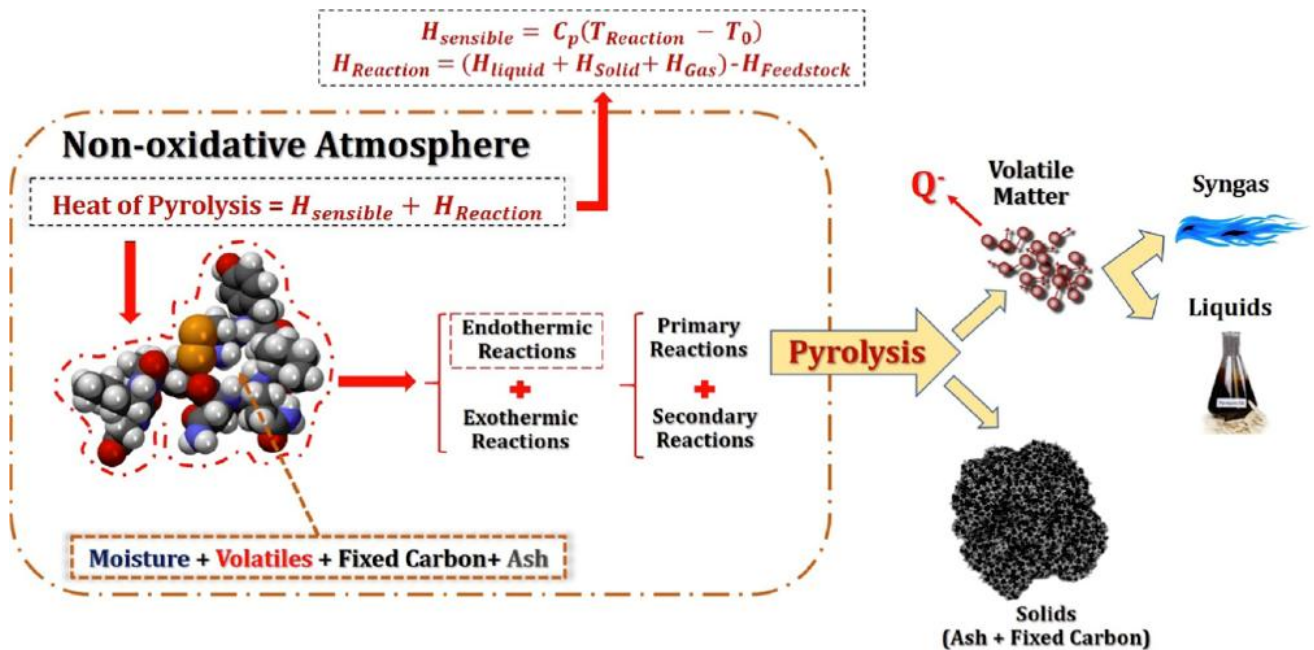


Figure 2.6 Schematic diagram of the pyrolysis process [27]

Slow Pyrolysis: Slow pyrolysis involves the gradual decomposition of materials at relatively low temperatures. It is characterised by low heating rates and relatively long solid and vapour residence times (approximately a few minutes to several hours). The extended residence time leads to secondary transformations of the primary products, resulting in increased production of char, tar, and thermally stable products. Consequently, slow pyrolysis is also known as carbonisation. Unlike fast pyrolysis, the aim of slow pyrolysis is to produce char, although tar and gas are also obtained, they are not necessarily recovered.

Fast Pyrolysis: In contrast to slow pyrolysis, fast pyrolysis signifies a higher heating rate. This process typically requires small particle sizes of feedstock and

specially designed equipment to remove rapidly released vapours. The high heating rates, shorter residence times in the thermal zone, and rapid quenching of products (volatiles) favour the formation of liquid products. This occurs because the higher molecular weight substances released during the pyrolysis process are condensed into liquid products before undergoing secondary reactions that would decompose them into gaseous products. Thus, it is possible to obtain liquid fuels with higher calorific values. In fact, the primary purpose of fast pyrolysis is considered to be an effective conversion pathway for producing liquid fuels, chemicals, and derivatives, usually achieving high yields (typically around 50-60 wt% from rubber feedstock).

Fast pyrolysis is usually carried out in fluidised bed, entrained flow, ablative, or free-fall reactors, with reaction times ranging from milliseconds to seconds. It is generally accepted that the residence time of the volatiles must be less than 2 seconds [25]. Longer residence times may lead to secondary reactions, such as pyrolysing, which can significantly reduce the yield of organic compounds. Super-pyrolysis or ultra-fast pyrolysis refers to a specific form of fast pyrolysis conducted under conditions of higher temperatures (above 700°C), very short reaction times (far less than 500 milliseconds), higher heating rates (greater than 1000°C/s), and rapid quenching of products .

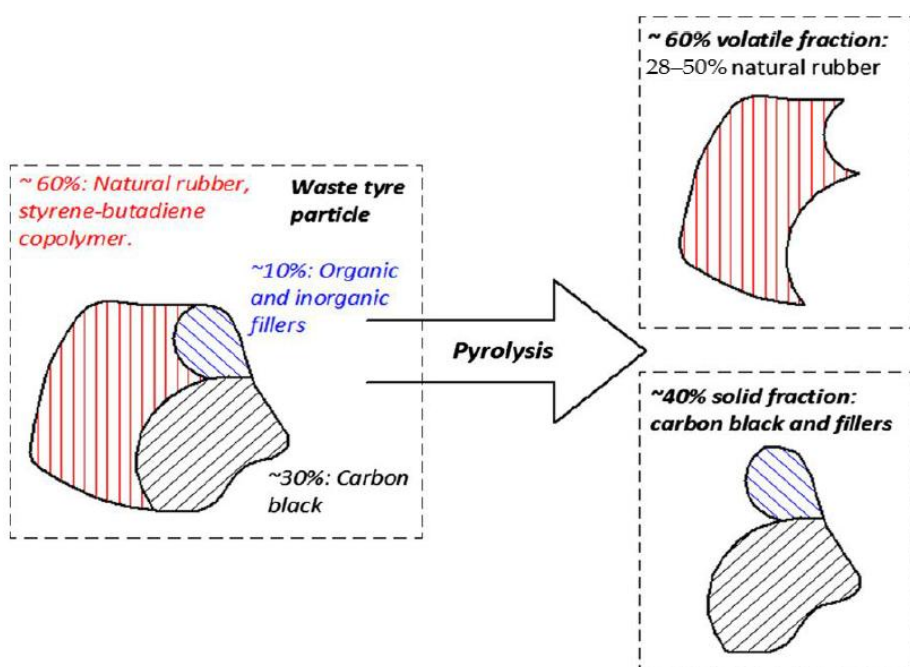


Figure 2.7 The pyrolysis process of SBR[15]

Catalytic Pyrolysis: Catalytic pyrolysis refers to any pyrolysis process in which catalytic materials are added during the pyrolysis to enhance or improve the yield or performance of certain products . For example, a core-shell catalytic composite material developed by Namchot[26] consists of a HY-zeolite core and a thin MCM-41 shell (50–100 nm thick), which reduces polycyclic aromatic hydrocarbons while enhancing the performance of the pyrolysis oil products and lowering the sulphur content in the products.

Co-pyrolysis: Co-pyrolysis refers to the simultaneous pyrolysis of waste tyres with other materials. This process generates synergistic effects that can offset the shortcomings of biomass in fuel production, thereby improving both the yield and quality of the fuel.

2.3 Introduction to pyrolysis reactor equipment:

The yield of pyrolysis products from waste tyres is primarily influenced by temperature, tyre particle size, heating rate, and residence time during the reaction. The three main products obtained from the pyrolysis of waste tyres—gas, liquid (oil), and solid (char, steel, and ash)—not only depend on the specific pyrolysis conditions but also on the type of reactor used. Historically, biomass was the first material to be pyrolysed, leading to the classification of reactors for biomass pyrolysis.

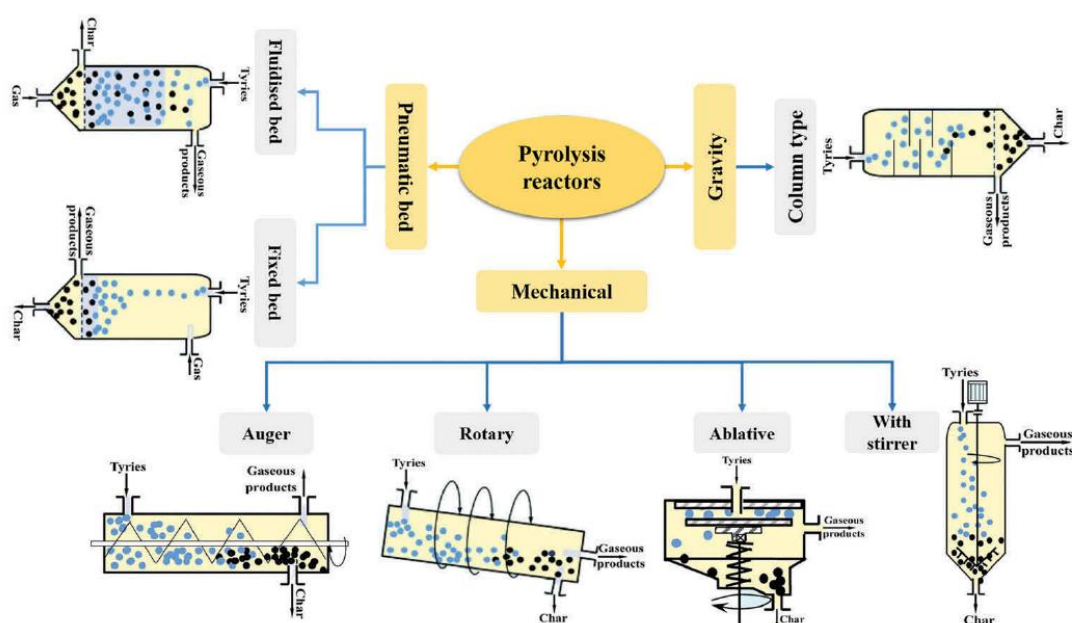


Figure 2.8 .Types of pyrolysis reactors.[28]

These reactors include various types, such as fixed, fluidised, spouted, circulating, vortex, or pneumatic rotating beds, as well as ablative, centrifugal, spiral, or mechanically operated reactors. Waste tyres, containing a significant amount of natural rubber, can also be regarded as a processed form of biomass, and various reactor designs originally developed for biomass pyrolysis—such as fixed bed (batch), rotary kilns, vacuum beds, and fluidised beds—have also been employed for the pyrolysis of waste tyres.

2.4 Waste tire pyrolysis products

2.4.1 Pyrolysis Oil

The pyrolysis oil obtained from waste tyres is a dark brown to black liquid with a medium viscosity and a sulphurous/ aromatic odour. The pyrolysis oil derived from tyres includes: (1) processing fluids used in tyre formulations, (2) organic additives, and (3) products from tyre pyrolysis. Pyrolysis oil is chemically very complex, containing over 100 identified compounds. The calorific value of waste tyre pyrolysis oil can reach approximately 44 MJ/kg, with the exact figure depending on the composition of the tyres and the processing conditions. Consequently, pyrolysis oil has a higher calorific value than the waste tyres from which it is recovered. Furthermore, the performance of pyrolysis oil is similar to that of light liquid fuels with comparable calorific value and sulphur content, making it a potential alternative to traditional liquid fuels. The formation of sulphur compounds in pyrolysis liquids is attributed to the thermal degradation of various additives (such as vulcanising agents and accelerators) used during the tyre manufacturing process.

Pyrolysis oil has been fractionated into a wide range of chemical components and is composed of aliphatic, aromatic, heteroatom-containing, and polar fractions. The main aromatic compounds found in the pyrolysis oil include benzene, toluene, xylene (dimethylbenzene), styrene, limonene, indene, and their alkylated homologues. Limonene ($C_{10}H_{16}$) is a high-value product present in tyre pyrolysis oil, commonly used in formulating industrial solvents, resins, adhesives, cosmetics, and

more.

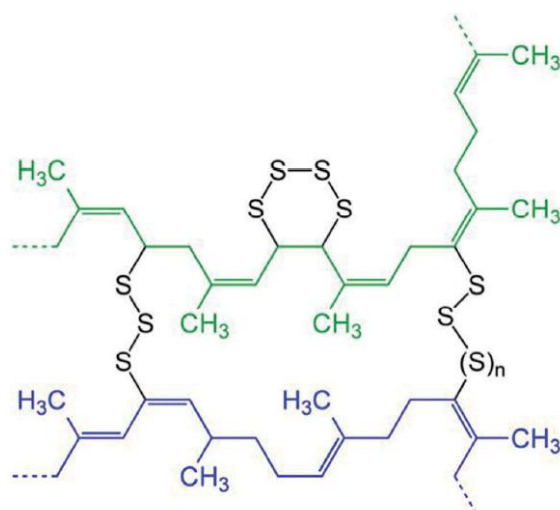


Figure 2.9 Cracking positions from ST molecule during pyrolysis.[28]

2.4.2 Pyrolysis Char

The solid residue from tyre pyrolysis is carbon, also referred to as pyrolysis char. Pyrolysis offers the potential to convert organic materials into carbon-rich solids. In the case of waste tyres, pyrolysis char corresponds to the fixed carbon and inorganic materials (such as Zn, Ca, and Si) used in tyre manufacturing. The composition of pyrolysis char depends on the pyrolysis conditions and the tyre's formulation, with its quality and yield being second only to that of the liquid products. Consequently, pyrolysis char significantly influences the economic feasibility of waste tyre pyrolysis.

2.4.3 Pyrolysis Gas

The gas produced during pyrolysis, after cooling and condensing to recover the pyrolysis oil, is referred to as pyrolysis gas or syngas. Pyrolysis gas typically consists of short-chain alkanes and alkenes, with carbon atom numbers ranging from 1 to 5. The overall composition of pyrolysis gas from tyres includes hydrogen (H₂), carbon monoxide (CO), carbon dioxide (CO₂), methane (CH₄), ethane (C₂H₆), ethylene (C₂H₄), propane (C₃H₈), propylene (C₃H₆), butane (C₄H₁₀), butylene (C₄H₈), and butadiene (C₄H₆), along with some low-concentration compounds of sulphur (H₂S, SO₂, COS, CS₂) and nitrogen (NH₃). The proportions of the gas components generated from waste tyres depend on the formulations of the various rubbers used in tyre

manufacturing, such as styrene-butadiene rubber, natural rubber (polyisoprene), nitrile rubber, chloroprene rubber, and polybutadiene rubber. The presence of C₄ compounds is primarily attributed to the thermal degradation of BR and SBR. The gas composition is influenced not only by the reaction temperature but also by the feedstock and experimental conditions, which may lead to certain secondary reactions. The thermal degradation process generates highly reactive free radicals, which are often subunits of the original rubber molecules. As the tyre rubber undergoes thermal degradation during pyrolysis, the main degradation products result in a high concentration of olefins, particularly dienes and butadiene. While pyrolysis gas has a relatively high heating value, its range can vary significantly, with reported values between 20 MJ·m⁻³ and over 65 MJ·m⁻³, depending on the gas composition, which is influenced by pyrolysis temperature, heating rate, reactor type, and other factors.

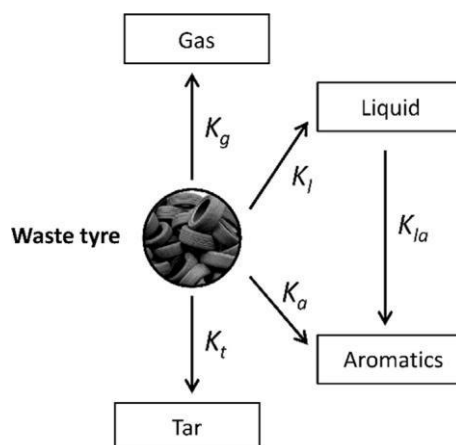


Figure 2.10 Kinetic scheme of a model with secondary reaction.[14]

CHAPTER 3. AUTOMATIC SYSTEM FOR SORTING AND PYROLYSIS OF WASTE TIRES.

3.1 Used tire sorting and pre-processing system

The system begins by capturing high-resolution images of the tires using cameras or sensors. These images are then processed by advanced algorithms, such as machine learning and artificial intelligence, to identify and classify the tires based on criteria such as size, type, condition, and material composition. The system can distinguish between tires suitable for reuse, recycling, or disposal.

Once classified, the tires are sorted using robotic arms or conveyors. The robotic arms can pick and place tires in designated bins or areas based on their classification. The system can also integrate weight sensors to further refine sorting based on the weight of the tires, which is useful for recycling processes.

The control system is centralized, allowing operators to monitor and adjust settings through a user-friendly interface. It ensures efficient workflow, minimal human intervention, and optimized recycling processes. Additionally, the system can be designed for scalability and adaptability, able to handle varying volumes and types of tires, making it an essential tool for sustainable waste management in the tire recycling industry.

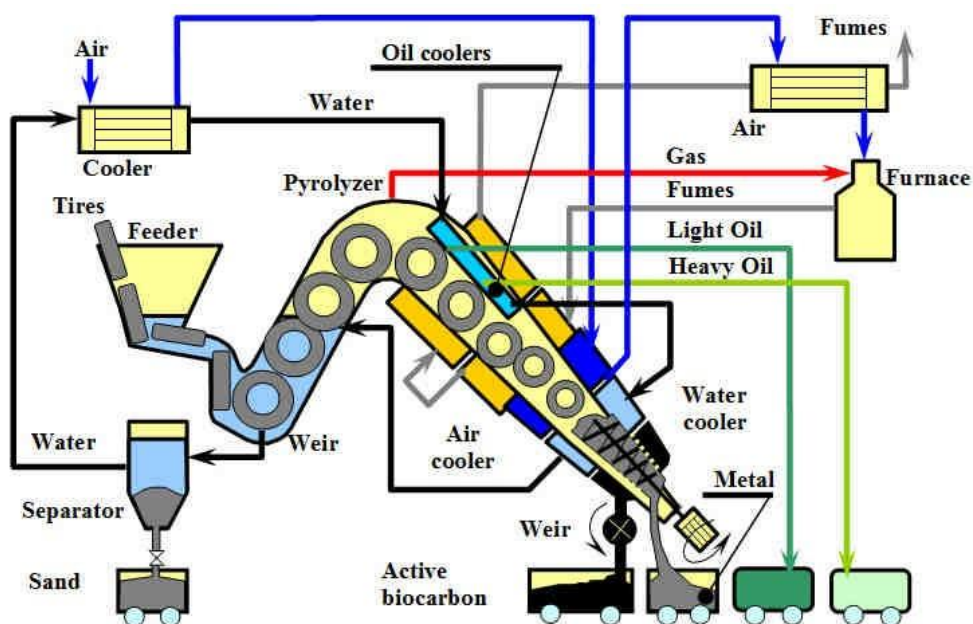


Figure 3.1 Schematic diagram of automatic system

The automated classification system for scrap tires is usually used to sort different types of scrap tires (such as size, material, degree of wear, etc.) according to their characteristics. The implementation logic of this system includes the following parts:

3.1.1. System process logic Used tire sorting and pre-processing system:

Input stage:

Data acquisition: Collect tire images, dimensions, weight and other information through sensors (such as cameras, laser scanners, weighing sensors, etc.).

Signal transmission: The collected signals are transmitted to the data processing module.

Data processing stage:

Feature extraction:

Image recognition extracts the appearance features of the tire (such as diameter, tread pattern, damage).

Physical features (such as weight, material) are read by sensors.

Classification logic:

Determine which category the tire belongs to based on machine learning algorithms or rule systems. For example:

Classify by diameter (small, medium, large).

Classify by degree of wear (renovable, severely damaged).

Classify by material (natural rubber, synthetic rubber).

Output control stage:

Execution control:

According to the classification results, trigger the corresponding robotic arm, conveyor belt or sorting device to distribute the tires to different areas.

3.1.2. Programming Logic for Used tire sorting and pre-processing system:

Our used tire classification and processing system is as follows, written in Python:

```
import cv2 # Image processing library
import numpy as np
```

```

# Simulate sensor data collection for physical characteristics
def get_sensor_data():
    # Simulate tire weight measurement
    weight = np.random.uniform(10, 50) # Unit: kg
    return weight

# Image feature extraction (e.g., diameter detection)
def analyze_tire_image(image_path):
    image = cv2.imread(image_path, cv2.IMREAD_GRAYSCALE)
    # Image preprocessing (e.g., edge detection)
    edges = cv2.Canny(image, 50, 150)
    # Simulate tire diameter calculation
    diameter = np.random.uniform(50, 100) # Unit: cm
    return diameter

# Classification logic
def classify_tire(weight, diameter):
    if diameter > 80:
        size_category = "Large"
    elif 60 < diameter <= 80:
        size_category = "Medium"
    else:
        size_category = "Small"

    if weight > 30:
        wear_condition = "Heavy"
    else:
        wear_condition = "Light"

```

```

    return size_category, wear_condition

# Sorting control
def sorting_control(size_category, wear_condition):
    if size_category == "Large" and wear_condition == "Heavy":
        print("Direct to: Severely Damaged Processing Area")
    elif size_category == "Medium" and wear_condition == "Light":
        print("Direct to: Retreadable Area")
    else:
        print("Direct to: General Recycling Area")

# Main program
def main():
    # Simulated image path
    image_path = "tire_sample.jpg"

    # Retrieve sensor and image data
    weight = get_sensor_data()
    diameter = analyze_tire_image(image_path)

    # Classification
    size_category, wear_condition = classify_tire(weight, diameter)

    # Sorting
    sorting_control(size_category, wear_condition)

if __name__ == "__main__":
    main()

```

3.1.3. Pretreatment before pyrolysis:

Before pyrolysis, waste tires need to undergo several preprocessing steps to ensure optimal efficiency and safety during treatment. The following steps are commonly required:

Removal of Contaminants: Tires should be cleaned to remove dirt, mud, and other contaminants that might interfere with the pyrolysis process or reduce the quality of the end products.

Bead Wire Removal: The steel wires embedded in the tire beads must be removed using specialized machines. This step prevents damage to the pyrolysis reactor and ensures better product purity.

Size Reduction: Tires are shredded into smaller pieces or chips using tire shredders. This increases the surface area, improving heat transfer and ensuring uniform pyrolysis. Typical sizes range from 2 to 5 cm.

Drying: Tires should be dried to remove excessive moisture, which can lower the efficiency of the pyrolysis process. The moisture content should ideally be below 2%.

Quality Standards:

Cleanliness: Tires should be free of mud, sand, and other contaminants.

Metal Removal: Over 95% of steel wires must be removed.

Size Uniformity: Shredded pieces should meet specified size requirements (e.g., 2-5 cm).

Moisture Content: Below 2% for efficient pyrolysis.

Proper preprocessing ensures consistent product quality, minimizes equipment wear, and enhances overall process efficiency.

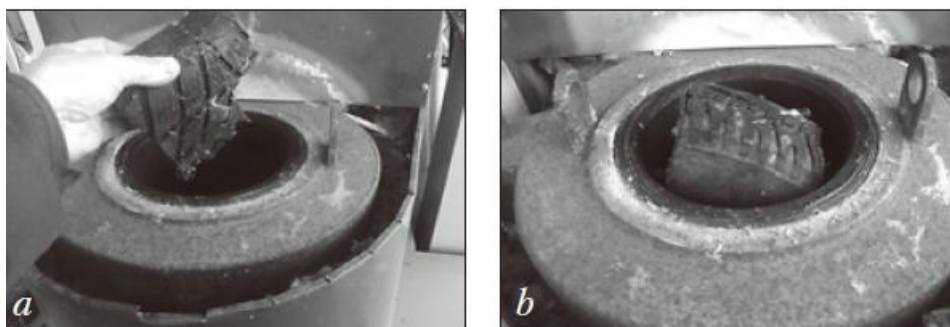


Figure 3.2 Pretreatment of used tires before thermal cracking. a) Crumb size, b)

Filling into the furnace [29]

Tire Shredding Equipment:

Purpose: Prepares tires for pyrolysis by reducing them to smaller pieces.

Manufacturer: Eldan Recycling

Model: Eldan Super Chopper (Shreds tires into smaller fractions)

Manufacturer: SSI Shredding Systems

Model: PRI-MAX PR780 (High-capacity shredder for heavy-duty operations)



Figure 3.3 PRI-MAX PR780 shredder equipment[30]

3.2 Used Tire Pyrolysis Process Control System

A process control system for used tire pyrolysis is essential to ensure efficient, safe, and consistent operation. The system typically integrates sensors, controllers, and software to monitor and manage various parameters in real time. Below are the key components and functions of the control system:

3.2.1. Composition and function of waste tire pyrolysis process control system:

1. System Components:

Temperature Control:

Sensors: Thermocouples or infrared sensors monitor reactor temperature.

Controllers: Adjust heating systems to maintain optimal pyrolysis temperatures (usually 300–500°C)[28].

Pressure Control:

Sensors: Pressure transducers measure reactor pressure.

Safety Features: Automatic pressure release valves to prevent over-pressurization.

Gas Flow Control:

Flow meters regulate the release and circulation of pyrolysis gases.

Systems ensure gases are directed to condensers or burned in secondary combustion units.

Feedstock Handling:

Automated conveyors or feeders regulate the input of shredded tires to ensure continuous processing.

Cooling and Condensation:

Heat exchangers and condensers are monitored to control the cooling rate and maximize liquid oil recovery.

Emission Monitoring:

Sensors measure gas emissions (e.g., CO, CO₂, SO₂) to ensure compliance with environmental standards[31].

Scrubber systems are integrated for pollutant removal.

Data Collection and Logging:

Programmable Logic Controllers (PLCs) or Distributed Control Systems (DCS) collect and log operational data.

User interfaces display real-time data for operator monitoring.

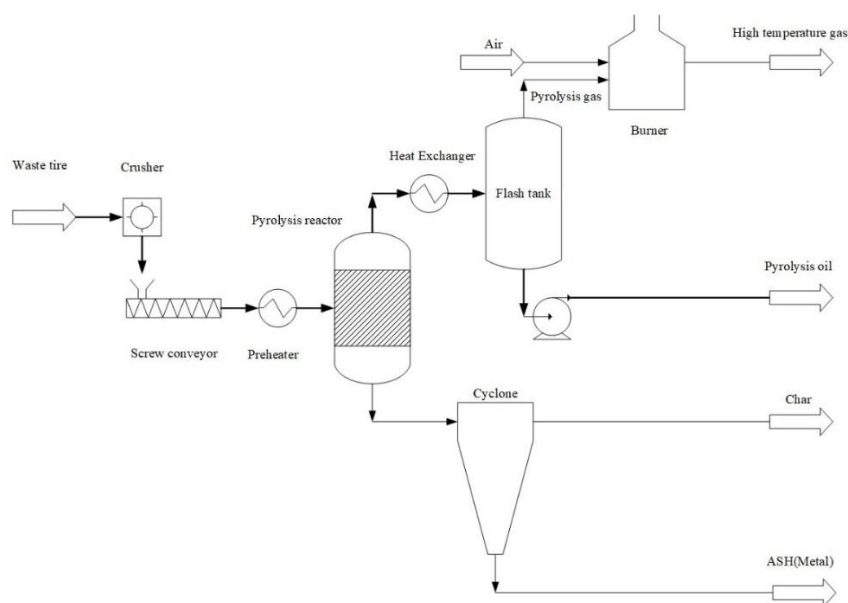


Figure 3.4 Used tire pyrolysis process flow chart

2. Key Functions:

Real-Time Monitoring:

Continuous data tracking for temperature, pressure, and gas composition.

Alarm Systems:

Alerts for deviations from set parameters, such as high pressure or excessive temperature.

Process Optimization:

Automated adjustments to maintain optimal operating conditions for maximum product yield.

Safety Protocols:

Emergency shutoff mechanisms in case of critical failures.

Remote Operation:

Advanced systems allow remote monitoring and control via software platforms.

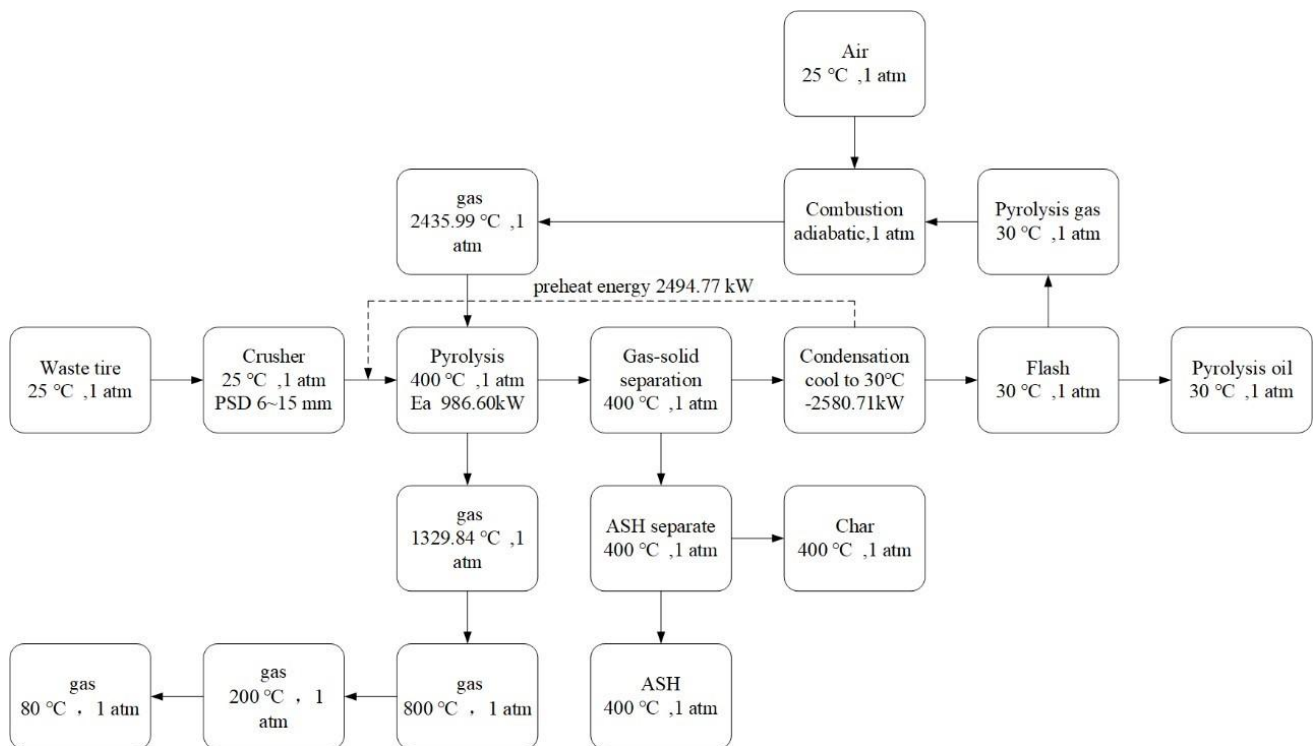


Figure 3.5 Used tire pyrolysis simulation process

3. Benefits:

Efficiency: Ensures consistent product quality and resource utilization.

Safety: Prevents accidents through real-time monitoring and automatic interventions.

Environmental Compliance: Minimizes emissions and environmental impact.

Cost Reduction: Reduces manual intervention and operational downtime.

3.2.2. Main equipment of pyrolysis treatment system:

1. Feeding system:

Use screw conveyor or belt conveyor.

Equipped with weighing sensor to monitor input quantity.

Automatic control logic:

Detect feed speed and automatically adjust conveyor belt speed.

Prevent overload and provide real-time feedback to PLC (Programmable Logic Controller)[32].

2. Pyrolysis Reactor

Heating: The reactor is heated to a temperature range of 400–700°C.

Oxygen-Free Design: Designed to operate in an oxygen-free environment to prevent combustion.

Equipped with Sensors and Controllers[33,34]:

Temperature sensors, pressure sensors, and flow controllers are integrated.

Control Logic:

Automatically preheats to the set temperature.

Adjusts heater power based on feedback from temperature and pressure sensors.

Automatically shuts down and triggers an alarm in case of abnormal temperature or pressure.

3. Product Separation System

Oil-Gas Separation:

Condensers cool the oil-gas mixture, collecting liquid oil while recovering or burning the gaseous components.

Steel Separation:

Magnetic separators extract steel wires.

Carbon Black Separation:

Cyclone separators or filtration systems collect carbon black.

Control Logic:

Automatically monitors condenser temperature to optimize cooling efficiency.

Real-time detection of steel separation efficiency by the magnetic separator.

Periodic cleaning of carbon black collection devices to prevent blockages.

4. Exhaust Gas Treatment System

Gas Combustion:

Non-condensable gases are treated using a gas burner.

Scrubbing Tower:

Purifies exhaust gas to reduce pollutant emissions.

Control Logic:

Real-time monitoring of exhaust gas concentration and flow rate.

Adjusts operating parameters of the burner and scrubbing tower as needed.

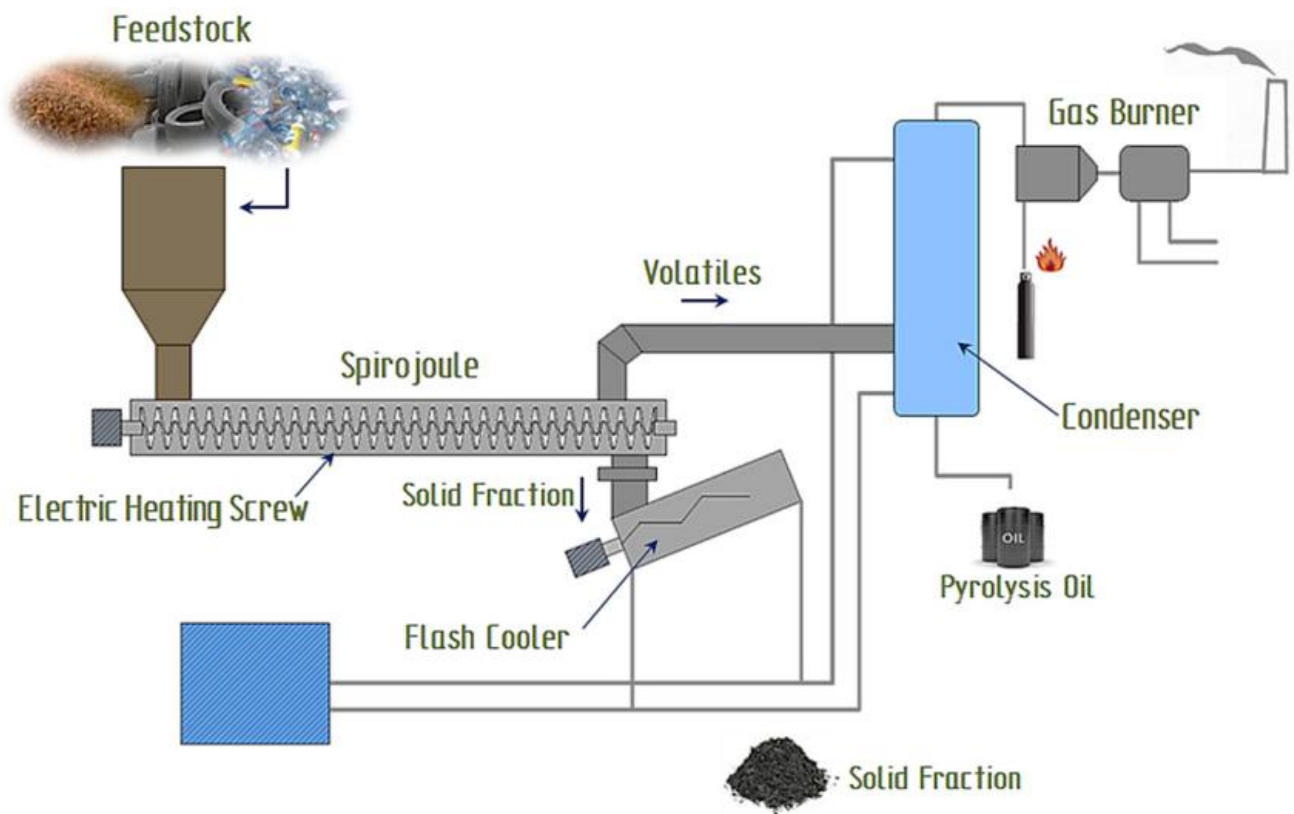


Figure 3.6 Schematic diagram of pyrolysis equipment system

3.2.2. Programming Logic for pyrolysis system:

The PLC program written in Structured Control Language (SCL) for the waste tire classification and pyrolysis process. The program includes logic for system initialization, feeding, pyrolysis, separation, and shutdown.

```

// Waste Tire Pyrolysis Control Program in SCL
PROGRAM PyrolysisControl
VAR
    // Sensors
    FeedSensor: BOOL; // Detects tire feed
    TempSensor: REAL; // Measures reactor temperature
    PressureSensor: REAL; // Measures reactor pressure
    GasFlowSensor: REAL; // Monitors exhaust gas flow

    // Actuators
    ConveyorMotor: BOOL; // Controls conveyor belt
    Heater: BOOL; // Activates the heating system
    GasBurner: BOOL; // Controls gas burner
    SeparatorMotor: BOOL; // Activates separators

    // Set Points
    MaxTemperature: REAL := 700.0; // Max reactor temperature
    MinTemperature: REAL := 400.0; // Min reactor temperature
    MaxPressure: REAL := 5.0; // Max reactor pressure

    // Alarms
    OverTempAlarm: BOOL;
    OverPressureAlarm: BOOL;

    // States
    SystemRunning: BOOL;
    ShutdownInitiated: BOOL;
END_VAR

```

```

// Initialization Step
IF NOT SystemRunning THEN
    ConveyorMotor := FALSE;
    Heater := FALSE;
    GasBurner := FALSE;
    SeparatorMotor := FALSE;
    OverTempAlarm := FALSE;
    OverPressureAlarm := FALSE;
    ShutdownInitiated := FALSE;
    SystemRunning := TRUE;
END_IF;

// Feeding Process
IF FeedSensor THEN
    ConveyorMotor := TRUE; // Start feeding conveyor
ELSE
    ConveyorMotor := FALSE; // Stop conveyor if no material
END_IF;

// Pyrolysis Process
IF SystemRunning THEN
    // Heating Logic
    IF TempSensor < MinTemperature THEN
        Heater := TRUE;
    ELSIF TempSensor > MaxTemperature THEN
        Heater := FALSE;
        OverTempAlarm := TRUE; // Trigger alarm for over-temperature
    END_IF;

```

```

// Pressure Control
IF PressureSensor > MaxPressure THEN
    OverPressureAlarm := TRUE; // Trigger alarm for over-pressure
    Heater := FALSE;           // Stop heating in case of high pressure
END_IF;

// Gas Burner Logic
IF GasFlowSensor > 0 THEN
    GasBurner := TRUE; // Burn excess gas
ELSE
    GasBurner := FALSE; // Stop burner if no gas flow
END_IF;
END_IF;

// Product Separation Process
IF SystemRunning THEN
    SeparatorMotor := TRUE; // Activate separators for steel and carbon black
ELSE
    SeparatorMotor := FALSE;
END_IF;

// Shutdown Process
IF ShutdownInitiated THEN
    ConveyorMotor := FALSE;
    Heater := FALSE;
    GasBurner := FALSE;
    SeparatorMotor := FALSE;
    SystemRunning := FALSE;
END_IF;

```

3.3 The main equipments of the system.

1. Automatic sorting system

The automatic sorting system includes feeding and conveying system, intelligent identification system, automatic sorting device, crushing system, wire separation system, dust control and exhaust gas treatment system, intelligent control platform and other equipment[35,36].



Figure 3.7 Schematic diagram of Automatic sorting system

1.1 Feeding Conveyor System

Function: Transports bulk waste tyres to the classification and identification system.

Key Features: Anti-slip design with automatic feeding capabilities to accommodate tyres of various sizes.

Equipment Type: Belt conveyor or chain plate conveyor system.

1.2 Intelligent Identification System

Function: Automatically identifies tyre material, size, and wear level using sensors and algorithms.

Core Technologies:

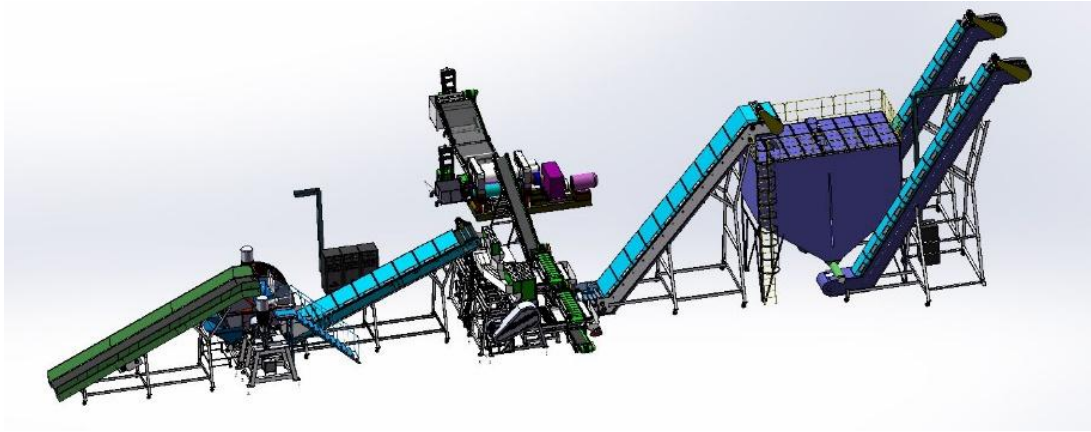


Figure 3.8 Schematic diagram of Automatic feeding system

Image recognition (utilising industrial cameras and AI algorithms).

Weight sensors to detect tyre body mass.

Output: Classification data to control sorting equipment for operation.

Cameras and Imaging Systems: High-resolution cameras, such as industrial-grade CCD or CMOS sensors, are needed to capture detailed images of the tires. These cameras should be equipped with proper lighting (e.g., LED or infrared) to ensure clear and accurate image acquisition under varying environmental conditions.

Maybe we can choose Cameras and Imaging Systems of Model: Basler acA1920-40gm (GigE camera with high resolution for industrial image processing); FLIR Blackfly S (USB3 camera series with high frame rates and resolution) Vision Cameras (e.g., Omron FZ-V10) for automated inspection and recognition tasks.



Figure 3.9 Cameras Model: Basler acA1920-40gm (GigE camera with high resolution for industrial image processing)[37]

Sensors: Different types of sensors, such as proximity sensors, weight sensors, and pressure sensors, are used to gather data about tire characteristics, including size, weight, and physical condition. These sensors provide additional information that helps refine the classification process.

The displacement sensor is Keyence IL Series, the weight sensor is Honeywell Weight Sensors, and the tire surface status detection sensor is SICK Ranger3

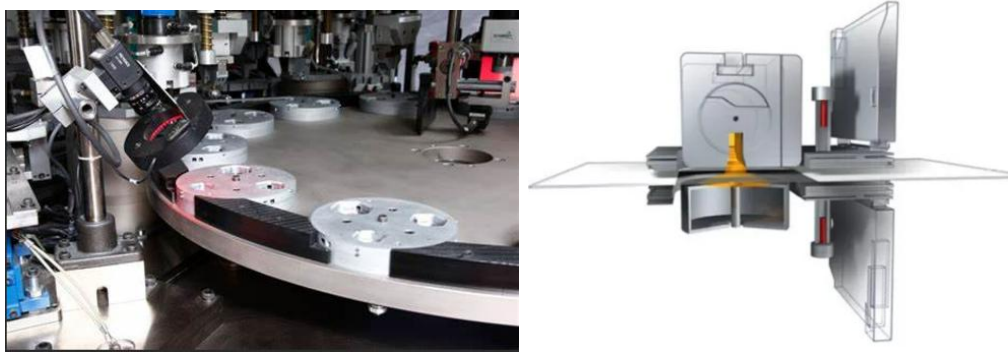


Figure 3.10 Schematic diagram of displacement sensor and weight sensor

Computing Unit (Server or Workstation): A powerful computing unit, often equipped with high-performance processors and GPUs, is necessary to run image processing algorithms, machine learning models, and control software. This unit handles data processing and decision-making for tire classification.

Robotic Arms or Conveyors: Robotic arms are required for sorting and handling tires once they are classified. These robotic systems are equipped with grippers or suction devices to pick up, move, and place tires into different categories or storage areas. Conveyor belts are used to transport tires to different stages of the process.

Control System Interface: An industrial control panel or a touchscreen interface is required to manage and monitor the system. The interface allows operators to adjust parameters, set up workflows, and monitor system status in real-time.

Motor Drives and Actuators: Motors and actuators control the movement of robotic arms, conveyors, and other mechanical parts. They enable the automation of tire handling and sorting tasks.



Figure 3.12 Schematic diagram of Shredding System[38]

1.5 Steel Wire Separation System

Function: Extracts steel wire from shredded tyres.

Equipment Types:

Magnetic separators (to remove steel wire).

Vibrating screens (for further separation of small steel residues).

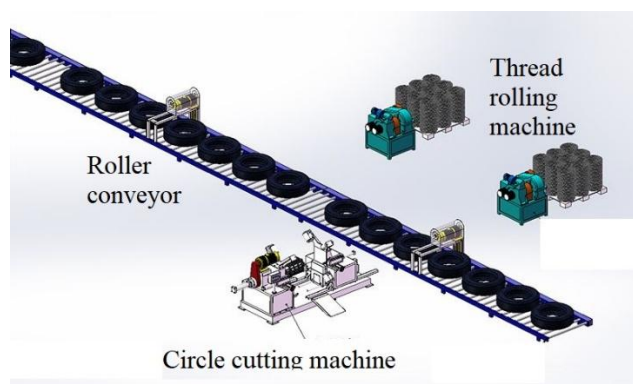


Figure 3.13 Schematic diagram of Steel Wire Separation System

1.6 Dust Control and Exhaust Gas Treatment System

Function: Manages dust and odours generated during shredding, ensuring a safe working environment and compliance with environmental standards.

Equipment Types:

Dust collectors (bag filters or electrostatic precipitators).

Exhaust gas purification units (activated carbon adsorption or wet scrubbers).

1.7 Intelligent Control Platform

Function: Provides centralised monitoring and intelligent operation of all equipment.

Technical Support:

Real-time data collection and analysis.

Fault alarms and remote debugging capabilities.

2. Pyrolysis Reactors:

Purpose: Conducts thermal decomposition of tires in an oxygen-free environment.

Manufacturer: DOING Group

Model: DOING Fully Continuous Pyrolysis Plant

Manufacturer: Kingtiger Group

Model: Kingtiger Continuous Pyrolysis Reactor

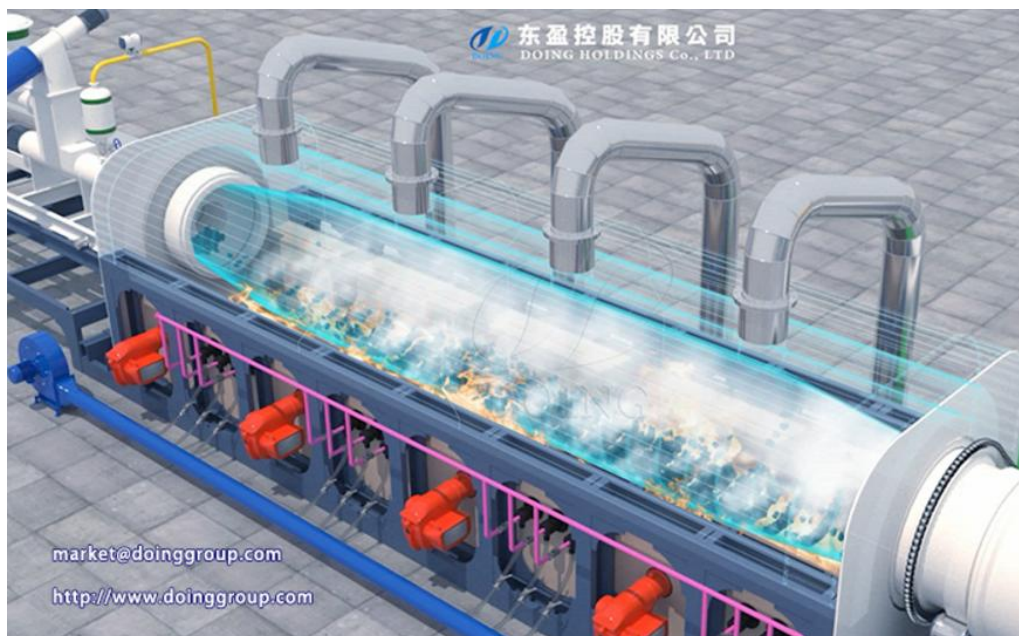


Figure 314 Schematic diagram of DOING Fully Continuous Pyrolysis Plant

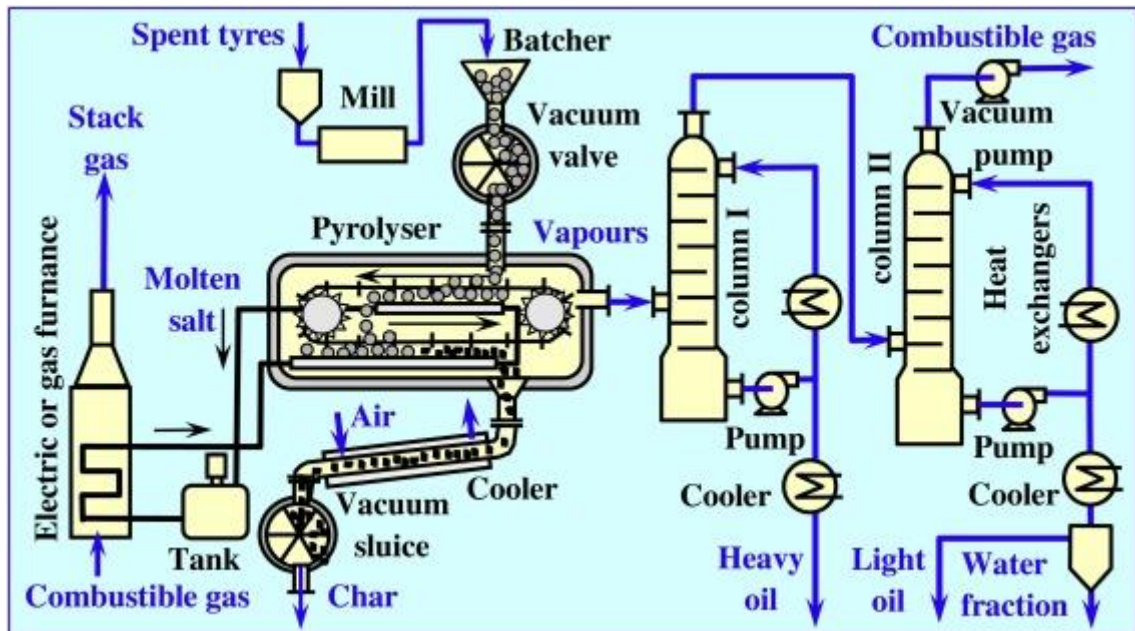


Figure 3.15 Flowchart of the Pyrocycling for used tire pyrolysis process[33]

3. Condensation and Cooling Systems:

Purpose: Condenses pyrolysis gases into liquid oil.

Manufacturer: PyroTech Energy

Model: PyroTech Condensation System



Figure 3.16 Pyrolysis system

4. Carbon Black Collection and Filtering System:

Purpose: Collects and purifies carbon black for reuse.

Manufacturer: Alfa Laval

Model: High-Speed Centrifuge

Home > Centrifuges > High Speed > Avanti J-26S Series



Avanti J-26S Series

The Avanti® J-26S centrifuge series combines high performance, complete BioSafety systems, and long-term durability, making it an incredibly capable choice for any lab environment. Experience simplified high-throughput sample processing and more control with powerful features including:

- ✓ Automatic rotor identification
- ✓ Low heat output
- ✓ Imbalance tolerance
- ✓ Quiet performance
- ✓ Ergonomic design features

RESOURCES + TOOLS

Figure 3.17 Photo and information of High-Speed Centrifuge Avanti J-26S Series[39]

5. Steel Wire Separators:

Purpose: Separates steel wires after pyrolysis for recycling.

Manufacturer: Eco Green Equipment

Model: ECO Steel Removal System

6. Gas Cleaning Systems:

Purpose: Removes impurities from gases generated during pyrolysis.

Manufacturer: Dürr Systems

Model: Dürr Ecopure® Tar

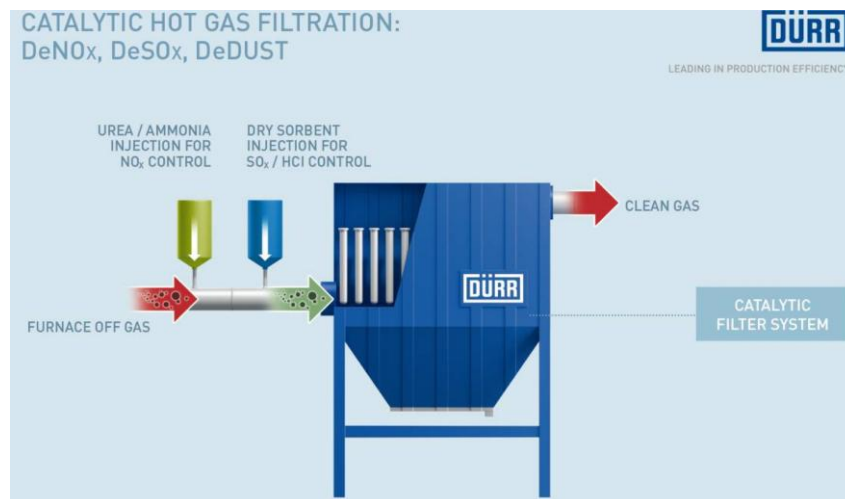


Figure 3.18 Schematic diagram of Gas Cleaning Systems[40]

7. Control Systems

PLC (Programmable Logic Controllers): Centralized automation and monitoring of the sorting and pyrolysis processes.

Manufacturer: Siemens

Model: SIMATIC S7-1500

Manufacturer: Rockwell Automation

Model: Allen-Bradley CompactLogix



Figure 3.19 Schematic diagram of SIMATIC S7-1500 PLC[41]



Figure 3.20 Electrical Control Panel – Internal

The recycling process, specifically the reactor operation, is managed by a process control automation system developed by Sterling Systems & Controls, Inc. Typically, multiple reactors are manufactured and operated concurrently. This system for tyre recycling includes a desktop PC equipped with dual monitors, a PanelView Plus running Rockwell's FactoryTalk View ME (Machine Edition) automation software,

and bespoke engineering and software solutions provided by Sterling Systems & Controls. Additionally, the system features a PLC/Motor Starter control panel, which contains the PLC, main disconnect breaker, motor starters, and variable frequency drives (VFDs) for reactor operation. Integration with the company's network is achieved through Sterling Systems & Controls' WebCentral™ application software, providing seamless connectivity between process control and organisational systems[42].



Figure 3.21 Controlling Equipment

Sterling Systems & Controls, Inc. was responsible for designing and constructing all electrical and control panels, performing system integration, and customising application engineering. The company also implemented its WebCentral™ software, a browser-based solution that provides access to the system's database. WebCentral enables users to review historical data, generate reports, and adjust system parameters remotely, provided the PC is connected to the same network as the automation control system. With its browser-based design, WebCentral is user-friendly and intuitive, making it suitable for scenarios where multiple users require secure, reliable, and

straightforward access to control system information. In this specific application, WebCentral allowed users to view reactor data in graphical format, modify system settings, search for specific views, and print historical reports from a remote location[43].

8. Networking and Communication

Industrial IoT (IIoT) Systems:

Manufacturer: Cisco

Model: Cisco Industrial Ethernet Series

Manufacturer: Siemens

Model: SCALANCE X Series

This combination of equipment ensures efficient tire sorting and pyrolysis, enabling sustainable waste management while recovering valuable materials.

CHAPTER 4 STARTUP PROJECT

4.1 Goals and Stages of Implementation of the Control System

This chapter aims to define and justify the structure and functionality of the advanced positioning control system. By employing cutting-edge control algorithms, the system seeks to surpass existing solutions in terms of precision and reliability. A key innovation is the incorporation of advanced feedback mechanisms, which greatly minimize errors and enhance the system's responsiveness. To initiate this project, a comprehensive outline of objectives for each development phase is provided, as detailed in Table 4.1.

Table 4.1 - Goals of Phased Implementation of the Control System

Stages of Control System Implementation	Control System Phased Implementation Objectives
Preliminary Stage	Assessing user needs and identifying limitations in current systems.
Innovation and Novelty	Designing and advancing algorithms and technologies to outperform existing solutions.
Market Analysis	Analyzing competing market technologies through technical and economic comparisons.
Resource Allocation	Identifying required resources, including materials, labor, and technology, for successful implementation.
Financial Planning	Estimating the costs involved and determining a pricing strategy for the new system.
Investment Phase	Seeking investment opportunities and securing necessary funding.
Marketing and Sales	Developing sales channels, targeting potential users, and effectively segmenting the market.

4.2 Rationale for the Importance and Acknowledgment of the Innovative Concept in the Control System Project:

The proposed control system project addresses key challenges in current market solutions, offering a significant improvement in precision, reliability, and performance.

The integration of advanced control algorithms and sophisticated feedback mechanisms represents a pioneering approach that not only meets but exceeds existing technological standards. This innovation has the potential to redefine industry benchmarks, ensuring greater system responsiveness and reduced error margins. Furthermore, the idea's relevance is underscored by the increasing demand for higher efficiency and accuracy in control systems across various sectors, including manufacturing, automation, and robotics. As such, this project holds considerable promise for advancing the field and gaining recognition for its innovative approach and practical applications.

The development of this control system project builds upon the research and findings discussed in previous chapters, which identified the shortcomings and limitations of current control systems in similar applications. Addressing the emerging need for enhanced precision and efficiency, especially in critical fields like automation and robotics, this project presents an innovative solution that surpasses existing technologies.

This proposed control system offers exceptional precision and flexibility, making it ideal for applications where traditional systems fail to meet requirements. The analysis of issues within existing systems supports the need and viability of this novel approach. Table 4.2 provides an overview of the relevance and originality of the control system, outlining its potential applications and advantages for users.

The Content of the Idea	Application Directions	Benefits for the User
Advanced control algorithms for precision and reliability	Automation, Robotics, Industrial Processes	Enhanced accuracy, reduced operational errors, and improved system responsiveness
Integration of adaptive feedback mechanisms	Aerospace, Manufacturing, Medical Devices	Increased system adaptability to changing conditions, higher precision in complex environments

Energy-efficient and scalable design	Energy Management, Smart Systems, Consumer Electronics	Lower energy consumption, adaptability to various scales and applications, user-friendly interfaces
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Table 4.2 - Relevance and Novelty of the Control System Project Idea

4.3 Analysis of the Competitive Environment

The competitive landscape for control systems is characterized by a mix of established players and emerging innovators. Current market solutions primarily focus on basic functionality, often falling short in terms of precision, adaptability, and efficiency. However, there is a growing demand for more advanced systems that can handle complex, high-performance applications in areas like automation, robotics, and industrial control.

Key competitors in this field typically offer systems with limited scalability or precision, which creates an opportunity for more innovative solutions. Our proposed control system stands out by integrating advanced algorithms and feedback mechanisms that significantly improve performance metrics such as accuracy, response time, and error reduction.

Moreover, while some competitors are beginning to explore new technologies, the proposed system's unique combination of features positions it as a differentiated offering in the marketplace. Through continuous monitoring of emerging trends and competitor strategies, we can identify opportunities to refine the system further and ensure it remains competitive in both technical and economic terms.

The competitive environment for positioning control systems is both evolving and highly competitive. As outlined in Chapter 3, our system introduces several innovative features that differentiate it from existing solutions. To assess its market position, we begin by comparing our system with a leading competitor, emphasizing key technical and economic factors.

Table 4.3 - Technical and Economic Advantages

No.	Technical and Economic Characteristics	Our Positioning Control System	Nearest Market Competitor
1	Precision and Reliability	Superior accuracy with advanced control algorithms	Basic precision capabilities
2	Adaptability	High adaptability to diverse operational environments	Limited adaptability
3	Energy Efficiency	Optimized for reduced energy consumption	Relatively higher energy consumption
4	User Interface	Intuitive and userfriendly design	More complex user interface

To develop a more effective strategy and navigate the competitive landscape, a comprehensive SWOT analysis was conducted.

Table 4.4 - Expanded SWOT Analysis

Factors	Our Positioning Control System Assessment
Strengths	- Integration of state-of-the-art advancements in technology. - Exceptional accuracy and dependability, surpassing industry benchmarks. - Intuitive interface designed to improve usability. - Durable construction optimized for diverse industrial uses.
Weaknesses	- Increased upfront costs for development and production. - Necessity for specialized training to ensure efficient operation. - Reliance on advanced, high-quality components for manufacturing.

Opportunities	- Growing demand in fields such as automation and precision engineering. - Opportunities to establish strategic alliances with major industry leaders. - Potential to branch out into areas like robotics and intelligent manufacturing. - Prospects for international growth, particularly in developing markets.
Threats	- Competitors making swift technological advancements. - Uncertainty in the market and evolving industry regulations. - Threat of competitors offering lower-priced alternatives. - Risk of becoming outdated due to rapid innovation cycles.

The SWOT analysis highlights the importance of adopting a strategic plan that capitalizes on our strengths, including cutting-edge technology and exceptional precision, while mitigating weaknesses such as elevated costs and the need for specialized training. Promising opportunities for market growth and collaboration exist, but careful attention must be paid to challenges like swift technological advancements and intense competition.

4.4 Justification of Resource Provision of the Project

This section outlines the essential resources needed for the effective deployment of the positioning control system. These encompass material, financial, intellectual, human, intangible, and informational assets. Table 4.5 provides a detailed rationale for the capital investments critical to the project's success.

Table 4.5 - Justification of Capital Investments for Project Implementation
(Amounts in UAH)

Articles of Capital Investment	Amount (thousand UAH)
Direct Material Costs	

- Raw materials and materials excluding returned waste	2,240
- Purchasing semi-finished products and components	880
- Fuel and energy consumption	400
- Spare parts costs	880
- Other material costs	400
Direct Labor Costs	
- Wages for production workers	9,600
- Bonuses, incentives, compensation for production workers	4,800
- Vacation pay for production workers	2,400
- Other idle time costs for production workers	800
Social Deductions to the Pension Fund (22% of wages)	5,555.20
Costs for Fixed and Intangible Assets	
- Initial cost of assets involved in production (including transportation, installation, and dismantling)	800
Other Direct Costs	
- Research and development for innovative products	3,200
- Services from third-party enterprises (security, advertising, rent, etc.)	1,600
- Utility bills	2,400

- Loan returns and maintenance	1,200
- Direct other costs	2,400
Total Expenditures	
- Production management costs	8,000
- Fixed assets and intangible assets for general production	6,400
- Technology improvement and production organization	2,000
- Costs for maintenance of production premises	640
- Labor protection, safety equipment, and environmental protection	1,200
- Other general production costs	1,200
Total Capital Investments for Project Implementation	59,095.20

The table outlines the capital investments necessary for implementing the positioning control system, supporting precise financial planning. It encompasses all project aspects, including direct material and labor costs, as well as broader expenditures like production management and technological enhancements. This detailed budget plays a vital role in the project's strategic and financial management.

4.5 Key Activities and Key Partners

This subsection elaborates on the methods employed to achieve the objectives set for the development of the positioning control system. The key tasks and activities are summarized in Table 4.6, providing a clear overview of each step in the process.

Table 4.6 - Description of main activities

Name of Activity	Description of Activity	Activity Result

Problem Analysis	Investigating the challenges in precision control and adaptability	Identification of key issues and potential solutions
Process Study	Evaluating effective processes for enhanced control and precision	Modeling and simulation of the control system
Design Phase	Designing the control system and its components	Detailed drawings and design specifications
Production	Manufacturing parts and assembling the control system	Completed and functional control system unit
System Implementation	Setting up and integrating the system into the desired environment	Successful deployment and operational system

In addition to these activities, the success of the project is significantly influenced by collaborations with key partners. These partners provide essential resources and services critical for the project's execution. Table 4.7 lists the primary partners involved in this project.

Table 4.7 - Key Partners

Partner Name	Location	Legal Status	Role
Advanced Robotics Solutions Ltd.	Shanghai, China	Limited Liability Company (Ltd.)	Development of advanced robotic components for integration into the control system.
Basler AG[30]	Ahrensburg, Germany	Corporation	HD camera and image recognition system support
Beckman Coulter[32]	California, United States	Corporation	High speed centrifuge support

Dürr Group[33]	Stuttgart, Germany	Corporation	mechanical and plant engineering
University : Igor Sikorsky Kyiv polytechnic institute	Kyiv, Ukraine	Educational Institution	Research collaboration and testing, providing technical expertise and resources.

This section presents Tables 4.6 and 4.7, which summarize the primary activities and essential partners contributing to the development and deployment of the positioning control system. This organized framework enhances understanding of the project's workflow and the collaboration necessary for its successful execution.

4.6 Financial Justification of the Startup Project

The financial analysis of the positioning control system project involves a thorough examination of the cost price, covering all expenses related to manufacturing and delivering the system. In accordance with Accounting Standard 16 "Costs," the cost structure is categorized into five primary economic elements, as outlined in Table 4.9. This table provides an organized summary of the cost components, including direct expenses like materials and labor, alongside indirect costs such as depreciation and operational expenditures. This detailed cost breakdown is essential for assessing the project's financial viability and determining an accurate pricing strategy for the final product.

Table 4.8 - Production Costs by Economic Elements

Production Cost Element
Direct Material Costs
- Raw materials and materials (excluding returned waste)
- Purchasing semi-finished products and components
- Fuel and energy consumption
- Packaging and packaging materials
- Construction materials
- Spare parts

- Agricultural materials
- Other material costs
Direct Labor Costs
- Wages according to rates and tariffs
- Bonuses, incentives, compensation payments, vacation pay
- Payment for other unworked time
- Other labor costs
Social Deductions (22% on wages to the Pension Fund)
Depreciation of Assets
- Fixed assets and non-current intangible assets
- Other non-current tangible assets
Other Direct Costs
- Research and development costs
- Cost of works, services of third-party enterprises, and communal services
- Rent, loan repayments, and their maintenance
- Losses due to technological defects
- Costs of realized production stocks
- Bad debts, operational exchange rate differences, stock depreciation
- Fines, penalties, and other operating expenses
Total Expenditures

4.7 Target Groups of Potential Users

Users are the operators and technicians who directly interact with the electromechanical equipment and automated systems. Their primary concern is the operational efficiency, ease of use, and maintenance of the system. They will be the ones managing the system on a daily basis, and their role is to ensure that it operates smoothly and safely. Here's a closer look at the potential user groups:

1. Recycling Plant Operators

Description: Workers at tire recycling plants are directly responsible for operating the sorting and pyrolysis systems. They need systems that are easy to operate, reliable, and safe.

Needs: They require user-friendly interfaces, automated sorting technologies, and systems with clear, actionable data to ensure that the tire sorting and pyrolysis processes are functioning smoothly.

Examples:

Genan: A global leader in tire recycling with operations across Europe and North America.

Tire Recycling Inc.: A prominent U.S. recycler specializing in tire disposal and material recovery.

Why They Need It: Operators need systems that reduce manual labor and ensure that tire recycling operations run efficiently with minimal downtime.

2. Maintenance Technicians

Description: These users are responsible for the ongoing maintenance and repair of the system. They ensure that the system stays operational and is kept in optimal working condition.

Needs: Technicians need comprehensive technical documentation, maintenance schedules, and access to spare parts to keep the equipment functioning.

Examples:

Sustainable Tire Recycling Solutions: A company that employs technicians for the maintenance of its tire recycling and pyrolysis equipment.

Why They Need It: Reliable, well-documented systems with clear technical specifications and training materials are essential for minimizing downtime and ensuring proper functioning.

3. Logistics and Sorting Supervisors

Description: Supervisors overseeing tire sorting and recycling operations will need tools to monitor the flow of tires through the system, optimize sorting processes, and ensure operational efficiency.

Needs: These users require real-time data reporting, workflow monitoring tools, and effective resource management tools to keep the sorting process streamlined.

Examples:

Liberty Tire Recycling: A large tire recycling company with supervisors overseeing tire sorting and processing operations.

Why They Need It: Supervisors need systems that allow them to monitor tire inventory, manage resources, and ensure smooth operations.

4. Pyrolysis Operators

Description: Pyrolysis operators are responsible for overseeing the pyrolysis process itself, which converts used tires into valuable byproducts. They manage the reactor systems and ensure that they are operating under optimal conditions.

Needs: These operators need clear control interfaces, safety protocols, and monitoring tools to ensure that the pyrolysis units are functioning efficiently and safely.

Examples:

Pyrolyx: A company that operates pyrolysis plants for recycling tires and extracting valuable materials.

Carbon Clean Solutions: A company focused on pyrolysis and carbon recovery technologies.

Why They Need It: Pyrolysis operators require systems that help them optimize output, minimize risk, and ensure consistent product quality from the process.

5. Environmental Regulators and Inspectors

Description: Government inspectors or third-party auditors who ensure that tire recycling and disposal systems comply with environmental standards and regulations.

Needs: They require comprehensive data reporting, clear documentation on emissions, and a transparent view of the system's operations.

Examples:

U.S. Environmental Protection Agency (EPA): The federal agency regulating waste management and environmental standards.

European Commission: Regulatory bodies overseeing tire recycling and waste management in the European Union.

Why They Need It: Regulators need accurate, real-time data to ensure compliance with local, national, and international environmental standards.

4.8 Target Groups of Potential Consumers

Target Groups of Potential Consumers

Consumers are typically the entities that will purchase the system. They may do so either for direct use in their operations or as part of a business investment. The focus of consumers will largely revolve around the overall cost-effectiveness, operational scalability, and sustainability of the system. Let's explore each potential consumer group in more detail:

1. Waste Management and Recycling Companies

Description: These companies are directly involved in the management, processing, and recycling of waste materials, including used tires. They play a significant role in the collection, transportation, and processing of tires and are therefore a key target group for tire recycling systems.

Needs: These companies require efficient, scalable, and cost-effective solutions for handling large volumes of used tires. They are motivated by both regulatory compliance (to meet recycling mandates) and the economic benefits of turning waste into usable materials (such as oil, carbon black, and gas).

Examples:

Waste Management Inc.: North America's largest waste management company, offering comprehensive waste services and tire recycling.

Veolia: A global leader in optimized resource management and recycling services, focusing on minimizing waste and maximizing recovery of materials.

Why They Need It: The system provides these companies with a sustainable solution to manage tire waste, reducing landfill dependency and enabling a circular economy approach by converting waste into valuable byproducts.

2. Automotive and Tire Manufacturers

Description: Large automotive and tire manufacturers generate significant amounts of waste tires. These companies often seek efficient, environmentally-friendly ways to dispose of or recycle used tires and may look to integrate such systems into their supply chains.

Needs: The need is for end-of-life tire management solutions that allow them to extract valuable materials (such as carbon black, oil, and gas) from used tires, reducing production costs and environmental impact. They are also looking for systems that can meet regulatory standards in tire disposal.

Examples:

Michelin: A global leader in tire manufacturing that might integrate tire recycling technologies into their operations.

Bridgestone: Another prominent tire manufacturer focused on sustainability and the reuse of materials.

Why They Need It: Manufacturers are increasingly seeking sustainable solutions for their supply chain to reduce their environmental footprint. The pyrolysis technology allows them to reuse tire-derived oil and carbon black, which can be used in the production of new tires or other industrial products.

3. Energy Companies (Renewable and Alternative Fuel Providers)

Description: Energy companies that focus on renewable and alternative fuels could be key consumers of pyrolysis systems, as they can use the oil, gas, and carbon black produced from used tires as an energy source.

Needs: These companies require pyrolysis systems capable of producing alternative fuels, including tire-derived oil and gas, to diversify their energy sources and meet renewable energy targets.

Examples:

TotalEnergies: A large energy company investing in renewable energy sources, including biofuels and alternative fuels.

Neste: A major player in renewable diesel and jet fuel production, potentially utilizing tire-derived products.

Why They Need It: The pyrolysis system can help energy companies convert waste into renewable energy, which aligns with global initiatives to reduce reliance on fossil fuels and transition to sustainable energy sources.

4. Investors and Venture Capital Firms

Description: Investors and venture capital firms that focus on green technologies or sustainable investments are also likely to be consumers. They may purchase the system either as part of an investment strategy or to fund the development and implementation of such technologies at scale.

Needs: Investors are looking for systems that offer high returns on investment while also contributing to environmental sustainability. They are interested in the scalability and market potential of the pyrolysis technology.

Examples:

Breakthrough Energy Ventures: A venture capital firm focused on investing in breakthrough clean energy technologies.

Blue Horizon: A firm with investments in circular economy businesses, including tire recycling technologies.

Why They Need It: These firms are looking for sustainable, high-return opportunities that also have the potential to disrupt the traditional waste management and energy sectors.

While both consumers and users interact with the electromechanical equipment and automated systems for sorting and pyrolyzing used tires, their roles and needs differ significantly. Consumers are interested in the long-term financial benefits, operational scalability, and sustainability aspects of the system, while users are focused on the day-to-day operation, ease of use, and maintenance of the technology.

Table 4.9. Definition of Basic Development Strategies

Selected Project Development Alternatives	Market Coverage Strategy	Key Competitive Position Based on the Selected Alternative	Basic Development Strategy

High-Quality Equipment	Differentiated Marketing	Leader	Differentiation Strategy
Energy-Saving Technology	Concentrated Marketing	Breakthrough	Concentrated Strategy
Wide Application	Mass Marketing	Follower	Mass Strategy

4.9 Sales Channels for Electromechanical Equipment and an Automated System

The sales channels for electromechanical equipment and automated systems for sorting used tires and their pyrolytic disposal are crucial for reaching a diverse range of customers, from large industrial enterprises to small-scale recycling operations. Identifying the most effective sales channels will enable the product to be marketed efficiently, ensuring that it reaches potential consumers and users while maximizing sales opportunities. Below is a detailed analysis of the potential sales channels, along with examples of how each can be applied to this type of product.

1. Direct Sales (B2B Sales)

Description:

Direct sales involve the company's sales team engaging with businesses and organizations directly to pitch, negotiate, and sell the equipment. This is particularly effective for high-value, complex, and custom-built systems like the tire sorting and pyrolytic disposal equipment.

Key Activities:

Sales Representatives: Employ a team of experienced sales representatives who engage directly with potential consumers such as waste management companies, automotive manufacturers, and recycling facilities.

Product Demonstrations: Sales teams can organize live demos or virtual demonstrations for prospective customers, showcasing the system's capabilities in sorting and pyrolyzing tires.

Customized Solutions: Offer tailored solutions based on the specific needs of each business, including modifications to fit different types of production facilities or processing systems.

Examples:

Veolia or SUEZ Recycling & Recovery could be approached directly by sales representatives for bulk systems tailored to their recycling processes.

Tire Manufacturers (e.g., Bridgestone or Michelin) could be targeted directly with customized equipment designed to handle specific volumes and types of used tires.

2. Distribution Partnerships

Description:

Forming partnerships with distributors and dealers who specialize in industrial machinery, recycling equipment, and waste management solutions can expand the reach of the product to various regions and industries.

Key Activities:

Partnership Agreements: Work with established distributors who already have relationships with industries that would benefit from tire recycling technology.

Channel Support: Provide technical support, marketing materials, and training to help distributors sell the system effectively.

After-Sales Service: Offer ongoing support to distributors, ensuring they can assist customers with maintenance and troubleshooting post-purchase.

Examples:

McCloskey International: A company known for its industrial machinery distribution might help distribute the tire sorting and pyrolysis systems in North America.

R-Machinery: A European distributor of recycling technology that can offer systems for sorting and processing used tires across the continent.

3. Online Sales and E-Commerce Platforms

Description:

For products that can be sold to a wider range of small businesses or startups, online sales platforms can be an efficient channel. E-commerce sites can provide details, specifications, and even demonstrations via video content for potential buyers.

Key Activities:

Product Listings: Develop detailed listings on specialized industrial equipment marketplaces or B2B e-commerce platforms such as Alibaba, ThomasNet, or Made-in-China.

Lead Generation: Use digital marketing techniques like SEO (Search Engine Optimization) and SEM (Search Engine Marketing) to attract qualified leads interested in tire recycling systems.

Online Consultations: Offer online consultations to explain the product's benefits and features to potential consumers, especially for international buyers who prefer remote buying options.

Examples:

ThomasNet or Alibaba: Listing the tire sorting and pyrolysis systems on these platforms can help target global businesses looking for tire recycling solutions.

Etsy (for B2B solutions): Although Etsy is often associated with small businesses, it can be used to target niche groups looking for eco-friendly solutions.

4. Industry Conferences and Trade Shows

Description:

Trade shows and industry conferences provide a valuable opportunity to showcase the tire sorting and pyrolysis system to a concentrated audience of potential buyers, partners, and users.

Key Activities:

Exhibiting at Trade Shows: Participate in recycling, waste management, and automotive technology trade shows to directly reach a qualified audience.

Networking Opportunities: These events often allow direct interaction with decision-makers, engineers, and investors who can be critical to sales.

Workshops and Seminars: Offer presentations or workshops to educate potential clients about the technology's advantages and demonstrate its application in real-world scenarios.

Examples:

The Tire Recycling Conference: An event where tire recycling technologies are discussed, and businesses from across the industry meet.

The International Waste Expo: One of the world's largest waste management trade shows where industry leaders discuss innovations like automated tire sorting and pyrolysis.

5. Government and Public Sector Procurement

Description:

Governments and public sector entities that focus on environmental sustainability and waste management can be significant consumers of large-scale systems for sorting and processing used tires.

Key Activities:

Public Tenders: Respond to public sector tenders for waste management solutions, recycling facilities, and environmentally-friendly disposal technologies.

Government Grants and Subsidies: Governments often offer funding or subsidies to promote green technologies, making this an ideal target group for your system.

Partnerships with Municipalities: Partner with municipalities or government agencies responsible for waste collection and management to install automated tire sorting systems.

Examples:

U.S. Environmental Protection Agency (EPA): Government agencies focusing on waste management could partner for national tire recycling initiatives.

European Union: The EU's push for circular economy solutions and sustainable waste management could lead to large-scale adoption of tire pyrolysis systems across member states.

6. Licensing and Franchise Models

Description:

In certain markets, licensing or franchising the technology may allow other companies to manufacture and sell the tire sorting and pyrolysis systems, expanding the reach without direct involvement in every market.

Key Activities:

Licensing Agreements: Partner with local manufacturers or large corporations to license the technology in different countries or regions.

Franchise Opportunities: Allow businesses to set up franchises where they can operate under a recognized brand, providing tire recycling services and using the equipment as part of their operations.

Revenue Sharing: Licensees or franchisees pay a percentage of revenue in exchange for the right to sell the system.

Examples:

RubberMaid Recycling: A company focused on tire recycling might license or franchise this system to extend its operational footprint globally.

RMI Tire Recycling: By offering a franchise model, they could expand the use of the pyrolysis technology to multiple regions without direct ownership.

7. Strategic Alliances with OEMs (Original Equipment Manufacturers)

Description:

Forming strategic partnerships with manufacturers of recycling equipment, waste management machinery, and automotive components can provide mutually beneficial access to a broader customer base.

Key Activities:

Joint Ventures: Collaborate on product development, marketing, and sales efforts.

Bundled Sales: Offer the tire sorting and pyrolysis system as part of a larger package with complementary equipment (e.g., shredders, crushers).

Technology Integration: Integrate the system into existing machinery used by OEMs, creating a seamless solution for customers.

Examples:

Caterpillar Inc.: As a leading heavy equipment manufacturer, they could partner in developing integrated solutions for waste management systems.

Komatsu: Another machinery manufacturer that could collaborate on bringing tire recycling systems to the industrial market.

4.10 Project Initiation Risk Analysis for this Electromechanical Equipment and an Automated System

The successful initiation and execution of the electromechanical equipment and automated system for sorting used tires and their pyrolytic disposal project require a thorough risk analysis to identify and mitigate potential threats that could impact the project's feasibility, cost, timeline, and overall success. Risk analysis is essential to anticipate challenges, reduce uncertainties, and ensure that the system is implemented smoothly. Below is a comprehensive breakdown of potential risks during the project initiation phase and strategies to address them.

1. Technological Risks

a. Technological Complexity

Risk: The development and integration of advanced electromechanical equipment and automated systems for sorting and pyrolytic disposal may involve complex technologies that could result in unforeseen technical issues, delays, or failures.

Impact: Any malfunctions or inefficiencies could delay production and increase costs, undermining the system's reliability and effectiveness.

Mitigation:

Conduct thorough feasibility studies and prototype testing before full-scale production.

Collaborate with experienced engineers to ensure the technological requirements are feasible and scalable.

Implement rigorous quality assurance and control measures to test each component under real-world conditions.

b. Technological Obsolescence

Risk: The rapid pace of technological advancement may result in the product becoming obsolete before it hits the market, especially if competing technologies surpass the proposed system.

Impact: This could reduce market demand and render the system less competitive, leading to financial losses.

Mitigation:

Continuously monitor industry trends and emerging technologies to stay ahead of the competition.

Ensure the system is designed with scalability in mind to accommodate future upgrades and advancements.

2. Market Risks

a. Market Acceptance

Risk: The potential market for the sorting and pyrolytic disposal system may not be as large or receptive as expected, particularly if competitors already dominate the space or if the market is slow to adopt new technologies.

Impact: Limited market adoption could result in low sales volumes, making it difficult to recoup investment and generate profits.

Mitigation:

Conduct thorough market research to identify potential customers and their needs.

Offer a well-planned marketing campaign to highlight the advantages of the new technology over existing solutions.

Provide case studies and pilot programs to demonstrate the system's benefits and real-world applications.

b. Regulatory and Compliance Risks

Risk: The project could face challenges related to the approval of its technologies from regulatory bodies, especially in areas such as environmental impact and waste disposal.

Impact: Delays in regulatory approvals could stall project timelines, and failure to comply with regulations could lead to fines or product recalls.

Mitigation:

Engage with regulatory authorities early in the design phase to understand requirements.

Ensure the system complies with local, national, and international waste management regulations and environmental standards.

Obtain necessary certifications for environmental safety and compliance with industry standards.

3. Financial Risks

a. High Initial Investment Costs

Risk: The initial investment for developing the equipment and automated system, including research, design, and production, may exceed estimates, leading to financial strain.

Impact: Overspending during the project initiation could threaten the financial viability of the entire project and delay its completion.

Mitigation:

Develop a comprehensive budget that includes contingency funds for unforeseen costs.

Secure funding from multiple sources, including grants, investors, and loans, to reduce dependency on one source.

Implement cost-control measures throughout the project to ensure expenditures align with the approved budget.

b. Cash Flow Issues

Risk: The long development and manufacturing cycle may result in cash flow problems, especially if the project faces delays or requires more time to generate returns than anticipated.

Impact: Cash flow disruptions could delay production and prevent the timely execution of the project.

Mitigation:

Develop a clear financial plan and cash flow projections.

Utilize milestone-based funding or phased payments to ensure steady cash inflow as the project progresses.

Maintain a financial buffer for unexpected costs and delays.

4. Supply Chain Risks

a. Supply Chain Disruptions

Risk: The project may rely on specialized materials or components for the electromechanical system, which could be subject to supply chain disruptions due to global trade issues, natural disasters, or supplier insolvency.

Impact: Delays in material or component deliveries could lead to production bottlenecks and missed deadlines.

Mitigation:

Diversify suppliers to reduce reliance on single sources for key components.

Establish long-term agreements with suppliers to ensure priority access to critical materials.

Develop contingency plans to source alternative components if needed.

b. Quality of Components

Risk: The quality of the materials or components used in the system may not meet the required standards, leading to system failures or inefficiencies.

Impact: Poor-quality components can result in costly repairs, delays, or even product recalls, damaging the system's reputation and financial returns.

Mitigation:

Work with trusted suppliers with proven track records.

Conduct thorough testing of all components and materials before final assembly.

Implement a robust quality assurance program to maintain high standards throughout the production process.

5. Human Resource Risks

a. Skilled Labor Shortages

Risk: The project may face difficulties in recruiting skilled engineers, technicians, and operators with the expertise to design, manufacture, and operate the complex automated systems.

Impact: A shortage of qualified personnel could delay development, reduce operational efficiency, and increase labor costs.

Mitigation:

Invest in training and development programs to upskill existing staff.

Collaborate with educational institutions or industry experts to attract talent.

Consider outsourcing specific tasks or collaborating with third-party specialists to fill labor gaps.

b. Knowledge Gaps in Emerging Technology

Risk: There may be a lack of in-house knowledge regarding cutting-edge technologies, such as the latest advances in automated sorting systems and pyrolytic processes.

Impact: A lack of expertise can hinder the project's ability to innovate, troubleshoot, and refine the system, leading to delays or failures in development.

Mitigation:

Hire experienced professionals or consultants with expertise in automated systems, pyrolysis, and electromechanical equipment.

Invest in continuous learning and training programs to keep the development team updated with the latest advancements in technology.

6. Environmental and Social Risks

a. Environmental Impact

Risk: The environmental impact of the equipment, including the energy consumption, emissions, and disposal of the used tires, could raise concerns from environmental groups or regulatory bodies.

Impact: Negative environmental assessments could lead to public backlash, legal challenges, or delays in obtaining necessary permits.

Mitigation:

Conduct a detailed environmental impact assessment and design the system with sustainability in mind.

Implement green technologies to minimize environmental damage, such as energy-efficient operations and low-emission pyrolysis processes.

Engage with environmental groups and communities to ensure transparency and gain support for the project.

b. Social Resistance

Risk: There may be local resistance to new waste disposal technologies, especially if communities are concerned about the perceived risks or environmental harm of tire pyrolysis.

Impact: Public resistance could delay project approval, create negative publicity, or hinder the implementation of the system.

Mitigation:

Develop educational campaigns to raise awareness about the benefits of the system, such as reducing tire waste and generating valuable by-products.

Engage with stakeholders, including local communities and advocacy groups, to address concerns and gain support.

4.11 Project effectiveness and attracting investors

The success of any project, especially one involving innovative technologies like the electromechanical equipment and automated system for sorting used tires and their pyrolytic disposal, depends heavily on its effectiveness—both in technical terms and in its ability to attract investors. For such a project, a multi-faceted approach is required to ensure the system’s operational efficiency while also demonstrating its potential to investors as a viable, profitable, and sustainable solution. Below are key areas of focus for ensuring project effectiveness and attracting investors:

1. Demonstrating Technological Innovation and Viability

a. Cutting-Edge Technology

Effectiveness: The system integrates advanced automation and pyrolytic disposal technologies, offering innovative solutions to the growing issue of tire waste. Its ability to sort used tires and convert them into valuable by-products through pyrolysis makes it highly efficient and attractive to industries focused on waste management, recycling, and sustainability.

Attracting Investors: Investors are drawn to innovative solutions that have the potential to disrupt existing markets. By demonstrating the unique aspects of the technology (e.g., superior automation, high energy efficiency, eco-friendly disposal), the project can stand out from existing systems and position itself as a game-changer in tire recycling.

b. Technological Scalability

Effectiveness: The project must be scalable, meaning it should be adaptable to varying scales of operation—from small, localized systems to large, industrial-sized ones. This scalability enhances the system’s potential to meet the needs of different markets and locations.

Attracting Investors: Investors want to see that the system can grow and adapt to market demands. Scalability implies long-term profitability and market expansion, increasing the likelihood of a high return on investment (ROI). Demonstrating that the technology can handle a wide range of tire types and volumes strengthens its attractiveness.

2. Cost-Effectiveness and Operational Efficiency

a. Reduced Operational Costs

Effectiveness: The system should be designed to minimize operating costs while maximizing efficiency. This includes reducing the need for manual labor, minimizing energy consumption, and lowering maintenance expenses through automation and efficient engineering.

Attracting Investors: Cost-saving technologies are essential for investors. By showcasing the system's ability to reduce ongoing expenses (e.g., labor, energy, and material costs), the project becomes more financially attractive. A well-designed system will lead to lower operational costs and higher profit margins, which is crucial for securing investor support.

b. Sustainable Resource Utilization

Effectiveness: The system's pyrolysis process can convert used tires into valuable by-products, such as oil, carbon black, and steel, which can be reused in various industries. This not only helps reduce waste but also generates additional revenue streams, improving overall project profitability.

Attracting Investors: Investors are increasingly interested in projects that focus on sustainability and the circular economy. By demonstrating that the system can create valuable secondary products from waste tires, the project becomes more attractive to investors looking for both financial returns and environmental impact.

3. Market Potential and Demand

a. Growing Demand for Recycling Solutions

Effectiveness: The global issue of waste tire disposal is escalating, with millions of tires being discarded each year. Industries are increasingly looking for solutions that comply with environmental regulations and offer effective recycling methods. The proposed system addresses these needs by offering an automated and efficient method for tire sorting and disposal.

Attracting Investors: Investors are more likely to fund projects that address pressing global challenges. The growing demand for sustainable waste management solutions, especially in countries with strict recycling laws, makes this project an attractive investment. Showing market potential and identifying key sectors (e.g., waste management companies, manufacturing industries) can drive investor interest.

b. Regulatory and Environmental Incentives

Effectiveness: The project must ensure compliance with environmental regulations and standards, including those related to waste management, recycling, and emissions. By adhering to these regulations, the system can receive the necessary certifications, making it eligible for incentives, grants, or subsidies.

Attracting Investors: Investors are increasingly interested in projects that align with environmental, social, and governance (ESG) criteria. Demonstrating the system's compliance with global environmental standards, coupled with potential government incentives, can enhance its investment appeal.

4. Financial Feasibility and Return on Investment (ROI)

a. Robust Financial Modeling

Effectiveness: A comprehensive financial plan is essential to outline the project's capital requirements, projected expenses, expected revenue, and ROI. Financial modeling should consider the costs of development, implementation, operational costs, and expected savings or revenues from selling by-products.

Attracting Investors: Investors need a clear picture of the financial benefits. A well-structured financial model helps them assess the viability of the project and the

expected returns. Providing detailed projections of revenue streams from sorting and recycling, alongside clear timelines for ROI, will increase investor confidence.

b. Risk Mitigation Strategies

Effectiveness: Identifying potential risks—such as market fluctuations, supply chain disruptions, or technological challenges—and developing mitigation strategies is crucial to ensure the project’s long-term success. Risk management plans can help safeguard both operational and financial stability.

Attracting Investors: Investors seek projects with a clear risk management strategy. Addressing potential risks and demonstrating how they will be mitigated ensures that investors feel confident about the security of their investment. By minimizing uncertainties, the project becomes a safer bet for investors.

5. Strategic Partnerships and Collaborations

a. Collaboration with Industry Leaders

Effectiveness: Forming partnerships with key players in the waste management, recycling, or automotive industries can provide valuable support in terms of expertise, distribution, and access to capital. These partnerships can also help in streamlining the implementation process.

Attracting Investors: Strategic collaborations can reduce market entry barriers and increase the credibility of the project. Investors often favor projects that have industry backing and a solid support network. By securing such partnerships, the project can demonstrate its potential for success and attract investors who are already familiar with the partners’ reliability and market presence.

b. Access to Funding and Government Grants

Effectiveness: Governments and international organizations often provide grants or low-interest loans for projects focused on waste reduction, environmental sustainability, and technological innovation. Securing such funding can help reduce the financial burden on the project.

Attracting Investors: Public funding or subsidies lower the financial risks for private investors, making the project more appealing. By securing grants or participating in government-sponsored initiatives, the project can attract investors by showing that it has already received external financial support.

6. Marketing and Sales Strategies

a. Clear Value Proposition

Effectiveness: The system's value proposition—how it benefits users, addresses industry pain points, and delivers superior performance compared to existing technologies—should be communicated clearly to potential customers and investors. Highlighting unique selling points, such as automation, energy efficiency, or higher output, is essential.

Attracting Investors: Investors want to see a clear path to market success. A solid marketing plan that showcases the system's advantages, identifies target markets, and outlines growth potential can enhance investor confidence. The clearer the value proposition, the more likely it is to attract funding.

b. Strong Sales and Distribution Channels

Effectiveness: Developing a well-established sales strategy that includes both direct and indirect channels, such as partnerships with distributors, online marketing, and industry events, will facilitate the system's market penetration.

Attracting Investors: Investors prefer projects that have an established route to market. A solid sales strategy and the ability to scale the system across various regions and industries can demonstrate the project's growth potential, leading to greater investor interest.

4.12 Business model

4.12.1 Value Proposition

Environmental Benefits: Pyrolysis technology significantly reduces pollution caused by tyre landfilling and incineration, aiding in achieving carbon emission targets.

Economic Benefits: Converts used tyres into high-value by-products such as pyrolytic oil, carbon black, and recyclable steel, generating income for clients.

Technical Advantages: Automated sorting systems improve efficiency, minimise manual intervention, and ensure precise sorting and processing.

Sustainability: Promotes the development of a circular economy and supports clients in building a green supply chain.

4.12.2. Target Customers

Used Tyre Processing Companies: Businesses seeking efficient sorting and environmentally friendly disposal solutions.

Government and Public Agencies: Local governments and environmental departments aiming to achieve environmental goals with tyre management solutions.

Energy Companies: Businesses interested in alternative energy sources like pyrolytic oil.

Manufacturers: Industrial enterprises requiring carbon black as a raw material.

Circular Economy Investors: Companies and investors focusing on sustainability initiatives.

4.12.3. Revenue Streams

Equipment Sales:

Selling sorting and pyrolysis equipment to processing businesses or government agencies.

Service Income:

Providing equipment maintenance, technical support, and operational training services.

Delivering customised tyre management solutions.

Resource Sales:

Selling oil, carbon black, and steel recovered through the pyrolysis process.

Leasing Model:

Offering equipment leasing to smaller processing businesses, charging based on usage.

Carbon Credits:

Generating income through carbon credit savings from reduced emissions.

4.12.4. Key Resources

Research and Development: Advanced pyrolysis processes and automated sorting technologies.

Manufacturing Capability: Producing high-quality, modular sorting and pyrolysis equipment.

Data Systems: Intelligent software platforms to optimise sorting and operational efficiency.

Partner Network: Collaborations with suppliers, distributors, and recycling organisations.

Professional Team: Comprising engineers, environmental experts, and business development personnel.

4.12.5. Key Activities

Equipment Design and Manufacturing: Ensuring equipment meets client needs and maintains technological superiority.

Technical Support and Services: Providing training, maintenance, and continuous optimisation services to clients.

Market Expansion: Growing the customer base through marketing and partnerships.

R&D Innovation: Enhancing pyrolysis efficiency and improving sorting technologies.

Resource Recycling: Streamlining the recovery and sales process for by-products.

4.12.6. Partners

Equipment Manufacturers: Supplying components and technical support for the systems.

Logistics Companies: Managing the transportation of used tyres and distribution of by-products.

Environmental Organisations: Collaborating on setting technical standards and driving policy support.

Industry Associations: Sharing market insights and promoting industry innovation.

Research Institutions: Co-developing new technologies and optimising existing processes.

4.12.7 Customer Relationships

Long-term Partnerships: Establishing long-term equipment supply and service contracts with major clients.

Customised Services: Offering tailored solutions to meet specific client needs.

Technical Support: Providing 24/7 technical assistance and online monitoring services.

Training and Certification: Training client operational teams and issuing certifications.

4.12.8. Channels

Direct Sales: Promoting equipment and services through a dedicated sales team.

Online Platforms: Showcasing products and success stories on the company's website and industry platforms.

Partner Sales: Expanding market coverage through partnerships with environmental firms, government bodies, and energy companies.

Exhibitions and Conferences: Demonstrating technologies and equipment at industry events.

4.12.9. Cost Structure

R&D Costs: Investments in technology upgrades and new product development.

Production Costs: Expenses for equipment manufacturing, component procurement, and assembly.

Operational Costs: Technical support, customer service, and market expansion expenses.

Sales Costs: Salaries for sales teams, advertising, and channel development costs.

Logistics Costs: Transportation costs for equipment and used tyre recovery logistics.

4.12.10. Competitive Advantages

Technological Superiority: Efficient sorting and pyrolysis technologies delivering faster processing and lower costs.

Environmental Compliance: Adhering to stringent environmental standards, enhancing client trust.

High Automation Levels: Reducing labour costs while improving precision and efficiency.

Modular Design: Allowing easy expansion and upgrades to cater to different scales of operation.

First-Mover Advantage: Leading the emerging market with cutting-edge solutions.

4.12.11. Risks and Challenges

Technological Challenges: Maintaining technological leadership requires significant R&D investment.

Market Acceptance: Adoption and promotion of pyrolysis technology may vary across regions.

Policy Changes: Changes in environmental regulations could create opportunities or threats.

Competitive Pressure: Potential price wars or the emergence of alternative technologies in the market.

Equipment Maintenance: Ensuring long-term stable operation of equipment is crucial for customer satisfaction.

4.12.12. Sustainability and Social Impact

Reducing Environmental Pollution: Transforming waste tyres into resources, minimising pollution from landfilling and incineration.

Promoting Circular Economy: Converting waste into resources, creating new value chains for society.

Job Creation: Generating jobs in equipment manufacturing, operation, and maintenance.

Raising Industry Standards: Advancing the tyre processing sector towards smart and environmentally friendly practices.

4.13 Cost

The cost of this project mainly includes the following parts:

R&D Costs: Investments in technology upgrades and new product development.

Production Costs: Expenses for equipment manufacturing, component procurement, and assembly.

Operational Costs: Technical support, customer service, and market expansion expenses.

Sales Costs: Salaries for sales teams, advertising, and channel development costs.

Logistics Costs: Transportation costs for equipment and used tyre recovery logistics.

4.13.1 Labor and research cost

Table 4.10 – Structure of personnel and FOP, hryvnias.

Position	Form of payment	Number of employees	Salary (UAH)		
			in a month	per quarter	per year
Production staff					
Developer	rate	1	30,000	80,000	360,000
Engineer	rate	1	35,000	105,000	420,000
Seller	rate	1	28,000	70,000	336,000
In total			93,000	255,000	1,116,000
Social deductions to the Pension Fund (22%)			20,460	56,100	245,520
FOP			113,460	311,100	1,361,520

4.13.2 Equipment cost

Table 4.11 – Cost structure of equipment

Equipment	Unit Price (UAH)	Quantity	Total Cost (UAH)
Automated Sorting System	2,500,000	1	2,500,000
Pyrolysis Reactor	10,000,000	2	20,000,000

Gas Scrubber System	3,000,000	2	6,000,000
Carbon Black Refining Unit	1,500,000	1	1,500,000
Steel Extraction Module	800,000	1	800,000
Integrated Control System	1,200,000	1	1,200,000
Total Estimated Cost	-	-	32,000,000

4.13.3 Other cost

Sales channel costs 1,000,000UAH/year.

Logistics costs 300,000UAH/year.

Conclusions for startup project

Environmental Solution: The project offers an eco-friendly solution to tire waste by converting tires into valuable by-products like oil and carbon black.

Technological Innovation: The system utilizes advanced electromechanical design and automation, providing better efficiency and cost-effectiveness compared to traditional methods.

Market Demand: The growing need for sustainable waste management and recycling solutions creates a promising market for this technology.

Financial Viability: The project has strong potential for profit through the sale of by-products and cost-efficient operations.

Scalability: The system is adaptable to various industries and can be deployed on both small and large scales.

Cost Efficiency: The automated system reduces labor costs and increases operational efficiency, contributing to long-term savings.

Regulatory Compliance: The project meets environmental regulations, offering opportunities for government incentives and partnerships.

Challenges: The high initial investment and technological hurdles must be managed through strategic partnerships and risk management.

Next Steps: Focus on securing investment, partnerships, and refining the technology for successful deployment.

CONCLUSIONS

This study explores the development and application of electromechanical equipment and automated systems for the sorting of used tyres and their pyrolytic disposal. The following key conclusions and innovations have been drawn:

1.Enhanced Sorting Efficiency

The integration of advanced automated systems significantly improves the speed and accuracy of tyre sorting. By utilising machine learning algorithms and sensor technology, the system can categorise tyres by size, material composition, and wear condition, paving the way for more efficient downstream processing.

2.Innovative Pyrolysis Integration

The incorporation of pyrolysis technology into the system provides a sustainable method for tyre disposal, converting waste materials into valuable by-products such as carbon black, pyrolytic oil, and syngas. This approach minimises waste and contributes to a circular economy by creating a closed-loop resource recovery process.

3.Reduced Environmental Footprint

Compared to traditional disposal methods such as landfilling or incineration, the proposed system achieves substantial reductions in greenhouse gas emissions and environmental contamination. This environmentally friendly approach aligns with global sustainability goals and offers a scalable solution for tyre waste management.

4.Cost-Effectiveness through Automation

By automating the sorting and initial processing stages, the system reduces dependence on manual labour and lowers operational costs. This cost-efficient design makes the solution accessible to both large-scale recycling facilities and smaller operations.

5.Scalability and Adaptability

The modular design of the system allows for scalability and customisation to meet the specific requirements of different regions or industries. Its adaptability ensures compatibility with diverse tyre compositions and waste management infrastructures.

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