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A Review on Material and Energy Recovery from Waste Tyres

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Abstract

The tyre industry in Botswana produces and sells thousands of tyres annually generating volumes of waste tyres which contribute towards the country's waste management challenges. At the end of their useful life, most tyres end up at waste dumping sites while a small fraction is recycled or reused, posing a health, safety and environmental hazard. The same desirable that make tyres, such as immunity to biodegradation, chemical reagents and photochemical decomposition tend to make their disposal a challenge. On the other hand, the number of vehicles on Botswana roads is continuously escalating due to more affordable imports from Japan, thus increasing the demand for tyres. The scope of this study is to review methods employed to recover materials and energy from waste tyres. Shredded waste tyres have found applications in civil engineering such as making culverts, retaining walls, ravine crossings and highway embankments. Other miscellaneous uses include playground swings, doormats, shoe soles, etc. The use of pyrolysis technology as an energy and material recovery mode from waste tyres has been of great interest in past studies. On average a single passenger vehicle tyre has between 30000kJ/kg and 35000kJ/kg potential energy, this is much higher than that of coal and biomass of the same mass, with lower ash content. The process yields potentially three revenue streams being; oil, carbon black and synthesis gas. The economic feasibility of waste tyre pyrolysis is determined primarily by product price, production capacity and production cost. Further processing of the pyrolytic oil and char and having a sustainable market for the derived products can greatly improve the economics of the process.

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1. INTRODUCTION

In the quest to improve the standard of living for humankind, the industrial era began in the 18th century. The instigation of the industrial era was not without repercussions, mostly which had an adverse impact on the environment. Transport and mobility form a highly crucial part of today's modern world. The use of automobile vehicles has thus become essential to individuals and the business community worldwide and Botswana is no exception. This has resulted in a rapid mass production of tyres with a projected estimate of 3 billion tyres produced globally by 2019 [5]. Once these tyres are used up, they present an arduous disposal problem. They end up in stockpiles at landfills and back yards, taking up valuable space that could have otherwise been used for something else. The significant population and GDP growth, with the importation of cheap Asian second-hand model cars into the country, resulted in an exponential increase of vehicles on the road, thus increasing the demand for tyres in the country [3, 25].

Waste tyre materials and energy recovery offer a potential solution to mitigate health and environmental concerns brought up by large volumes of waste tyres. Whole unprocessed waste tyres may be used in construction due to their physical properties such as low thermal conductivity, light weight and high drainage capacity [20]. Previous studies have indicated that energy recovery from waste tyres is a valuable form of exploiting used tyres [2, 9, 14, 16, 18, 22, 24]. Pyrolysis of waste tyres yields amongst others pyrolytic oil which has potential major applications in the cement industry, steam and electricity generation [8, 27]. To improve the economic efficiency of waste tyre pyrolysis products further processing is required, thus, making the process more feasible, however, this is dependent on the production capacity and market demand [13, 15].

2. CHARACTERISATION OF TYRES

Tyres consist of four key parts (as shown in fig.1) namely; tread (in contact with the ground), plies (portion of the tyre on which tread is vulcanized), sidewall (absorbs shock from the terrain) and heels (fit casing to the rim) [20].

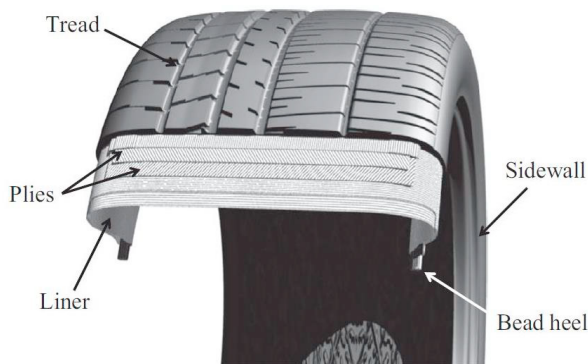


Figure 1: Transversal cut of a radial tyre[7]

Tyres mainly constitute of carbon black and rubber, carbon being the most element. Other constituents are added during the manufacturing process as fillers and accelerators. Table 1 shows typical average new tyre composition. This composition varies by tyre application and manufacturer. Tyre manufacturers keep this confidential as it is trade secret. After use this composition changes as about 10-15% the rubber on the tread wears out [13].

Table 1: Average composition of a new passenger and truck tyre [23]

COMPONENT	PASSENGER TYRE (wt%)	TRUCK TYRE (wt%)
Rubber	47.0	45.0
Carbon black	21.5	22.0
Metals (e.g. steel)	16.5	21.5
Textile (e.g. nylon)	5.5	-
Zinc oxide	1.0	2.0
Sulphur	1.0	1.0
Additives (e.g. clay, silica)	7.5	5.0

3. MATERIALS RECOVERY

Due to their ability to withstand harsh environmental conditions, tyres find several secondary applications. They may be used as shreds, cuttings and/or as whole tyres. Applications vary from simple use such as shoe soles, mats and outdoor furniture to more complex use such as culverts and road bed support.

The use of scrap tyres in construction has had a growing interest as they have been used for, lightweight fill, thermal insulation, drainage layers, and road bed support [26]. These applications are based on beneficial technical use and acceptable environmental impact. Lightweight fills are materials used to reduce stress on underlying soil to increase global stability of constructions an example is shown in figure 2 below. The use of tyre shreds provides a lower bulk density and high porosity and drainage compared to that of soil materials, thus, yielding a lower maximum water content[4]. The use of tyre shreds as lightweight fill is seen on road embankments and in noise barriers.

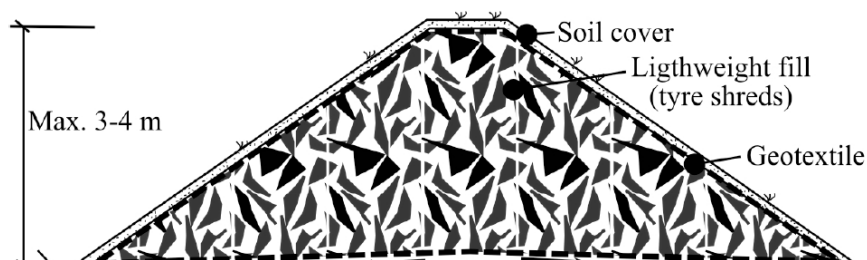


Figure 2: Example of lightweight fill

Due to their low thermal conductivity, waste tyres are also used for thermal insulation in road construction. Fine grained are susceptible to frost penetration at very low temperatures during the winter, which causes frost heave. The layer of tyres insulates the layer of soil underneath, combined with the high porousness of the material it reduces frost

heave by acting as capillarity breaking layer [4]. Whole large waste tyres as underground culvert is one other application of waste tyres in road construction which presents a cost-effective alternative. The tyre culverts were found to have good drainage properties, could carry a light truck and successfully diverted runoff water from buildings [26].

4. ENERGY RECOVERY

Energy from waste tyres is recovered mainly through their pyrolysis. Pyrolysis is an endothermic reaction in which the feed materials are decomposed at high temperatures of in the absence of air and/or oxygen. During pyrolysis, the feed material is not burned but rather larger molecules are broken down into smaller molecules. This typically occurs at temperatures ranging between 400°C and 800°C [16]. During the pyrolysis of waste tyres, the long chain polymer is broken down into shorter hydrocarbon gas, pyrolysis oil and char in the presence of a catalyst at temperatures around 500-600°C [20]. The entire process then yields;

- Non-condensable gas consisting of non-combustible e.g. carbon dioxide and combustible gases e.g. methane
- Liquid fraction known as pyrolytic oil
- A solid fraction consisting of metals, ash, aggregates and residual carbon.

The composition of the final products is determined by several factors, being; feed stock and size, reactor type, temperature and pressure, rate of heat transfer, catalyst used and residence time. The use of tyre shreds instead of whole tyres has been found to improve efficiency of the process by 20-30% [12]. Higher temperature pyrolysis tends to favour yield of more gases, whereas lower temperature pyrolysis usually produces more of the liquid fraction. As the liquid fraction is easier to handle, rapid quenching is often used to condense the gaseous fraction. A wide variety of reactors have been employed for this process, these include fixed-bed, fluidised-bed, rotary kiln and vacuum reactors. The type of reactor chosen depends on several factors including feedstock used, operating conditions, reactions and desired product. Figure 3 illustrates a simplified pyrolysis process.

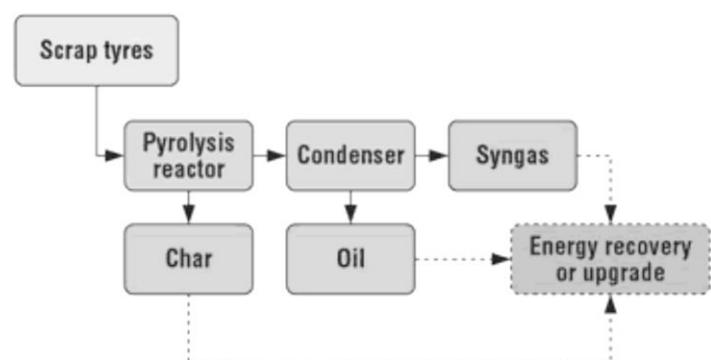


Figure 3: Simplified pyrolysis pathway

4.1. Pyrolysis products

4.1.1. Non-condensable gases

The pyrolysis derived gas makes up about 10-30wt% of waste tyre pyrolysis products depending on the operating temperature. It has a calorific value of approximately 30-40MJ N/m³ which may be used to run a pilot plant [13]. The predominant gases are the C₄ and <C₄. The gas also consists of carbon oxides (CO_x), hydrogen sulphide (H₂S), alkanes and alkene gases from methane (CH₄) up to hexene (C₆H₁₂) [12]. The high concentrations of methane and ethane in pyrolytic gas gives it potential to be used as a fuel. About 10-15% of the gas may be re-introduced into the process to enhance performance, thus potentially increasing thermal efficiency to 90% [16]. The rest may be compressed and stored for future use or supplied to boilers and internal combustion engines.

4.1.2. Pyrolysis oil

With the depletion of fossil fuels and emission challenges there has never been a greater need for greener alternative fuels. Pyrolytic oil has a high gross calorific value reported to be ranging between 37 - 44MJ/kg which is significantly higher than that of unprocessed waste tyres, 33MJ/kg and bituminous coal, 28MJ/kg [13]. The tyre derived oil is a complex mixture of hydrocarbons primarily consisting of alkylated benzenes, naphthalenes, phenanthrenes, n-alkanes from C₁₁ to C₂₄, and alkenes from C₈ to C₁₅, sulphur and oxygenated compounds [16]. The oil from waste tyres is similar to No. 6 oil which is the lowest grade of fuel oil as it is a thick, black tar-like liquid [15]. This oil could be used as liquid fuel for industrial boilers, furnaces and power plants after further refining as it is chemically complex. The olefins in the pyrolytic oil is similar to that of condensates from petroleum residues cracking and steam cracking of gasoline, hence they may be blended [16]. In comparison with commercially available petroleum diesel, the gross calorific values are similar as that of diesel is reported to be about 46MJ/kg [19]. This further supports the possibility of blending pyrolytic oil with diesel or using it as an alternative fuel to diesel. This is further supported by studies on using diesel and pyrolytic oil blends in internal combustion engines which showed no adverse effects to the engine [6, 11, 21].

4.1.3. Pyrolytic Char

The utilization of pyrolytic char depends on a number of factors, such as; chemical composition, pigment, adsorption activity, and other colloidal properties [1]. In recent years its uses have expanded to include pigmentation, ultraviolet (UV) stabilization and conductive agents in a variety of everyday and specialty high performance products such as electronic-discharge compounds (ESD), plastics and printing inks [1, 17]. To augment the commercial value of waste tyre pyrolytic carbon black and increment its potential application as activated carbon, further treatment such as chemical activation is vital. The activated carbon may be used for fuel cells and air and water purification [1]. Other studies showed that as pyrolytic char is similar to carbon black it may be replaced by semi-reinforcing commercial blacks employed in conveyor belts, footwear and dock fenders [10].

5. CONCLUSION

Due to their ability to withstand harsh conditions, tyres are a very good resource. The raw materials that could be derived from waste tyres provide an environment pollution solution and economic effective pathway. Although tyre derived fuels are in early stages of implementation, they have the potential to be a key alternative renewable energy resource. The lack of widespread use of this technology and commercial implementation is due to some major economic problems relating to high energy input requirement of the process, product marketability, product quality and product prices.

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