Waste to Energy; Disposable Tires to Carbon Fuel

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Abstract

Nowadays, Jordan faces significant environmental pollution because of the huge amounts of disposable tires filled in its landfills. This work is established to solve this environmental problem that Jordan and especially Aqaba face, and this is done by converting disposable tire waste into industrial briquette carbon fuel. The raw material used in the process is pyrolytic black carbon, which comes from the tire pyrolysis plant as a by-product material, and this raw material is considered waste without further processing (the main problem). Waste-to-energy technology was applied, and the main and big result of this work is a high calorific value of 28 MJ/kg for industrial briquette carbon fuel compared to coal at 20.7 MJ/kg and commercial black carbon at 21.56 MJ/kg, which makes the industrial briquette carbon fuel produced in this work valuable fuel and favorable for industrial plants, especially cement plants.

Keywords: Tires, Waste material, Pyrolysis Process, Bio Energy, High calorific fuel, Carbon fuel, Environmental and health.

1. Introduction

Energy demand in the 21st century is rising day by day, and due to the growing population, Jordan needs new renewable fuels to meet its energy requirements. Disposable tires waste today is a significant and unlimited growing problem affecting the health and whole ecosystem. 1.5 billion tires are sold worldwide yearly (Mohajerani et al. 2020), which means 4 billion tons of tires are weighted as scrap and considered a considerable amount to throw into the environment after using it (Gharaibeh et al. 2021). 2.5 million tons of disposable tire are generated in Jordan each year (Gharaibeh et al. 2021).

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Municipal solid waste (MSW) includes several types of wastes such as household material garbage, plastic, construction waste, tires, and other wastes, considered chronic environmental problems, harmful health effects, and create economic problems worldwide (Meena et al. 2019). The waste tires are considered toxic when exposed to direct and open burning; the most famous of these toxic chemicals are; CO_2, NO_X, SO_X, CH_4, ash, and some other toxic materials (Sipra et al. 2018). Many usable tires are thrown out to the landfills without any treatment yearly. This amount is estimated to be almost 50% which is considered as a significant environmental problem today (Gigli et al. 2019). These wastes can be managed by thermochemical or biological methods. The thermochemical method uses more than biological one and includes incineration, gasification, and pyrolysis process. On the other hand, the biological method includes fermentation and anaerobic digestion.

The pyrolysis process is the most preferred option for usable tires management, and it is used as an alternative method for incineration. This process reduces the volume of usable tire waste in the environment by converting solid waste tires into three valuable products: pyrolysis oil, pyrolysis black carbon, and gases.

In the present work, pyrolysis black carbon processed to produce industrial briquette carbon fuel with high calorific value and carbon content, in addition to low moisture content.

1.1. Tires

The first wheel in this world was invented in 3500 BC, becoming one of the greatest innovations in that time. Leather was used in vehicles to make the ride easier and softer, and with time, they started to use solid rubber without air for slow-moving vehicles (Liu et al. 2021). Today, tires are known as one of the leading engineered items, and their fabrication could be a well-established prepare which includes tight quality controls (Bowles et al. 2020). They are planned to perform several capacities, such as giving versatility, security, and consolation to the travelers of a vehicle beneath extraordinary conditions (Sienkiewicz et al. 2017). Almost all tires have the same or close group of materials but different designs (Januszewicz et al. 2020a).

1.2. Disposable Tire Problem in Aqaba

In February 2019 and December 2022 (Al’anbat and Alghad), the news reported about the pollution that the waste of usable tires emitted and the diseases they caused when they burned, and this problem has existed until now as shown in **Figure 1.**

Figure 1. Tires waste stream in Aqaba's landfill.

This work solved two environmental problems exist in Aqaba-Jordan mainly. The first problem was throwing out big amounts of disposable tires into landfills area which caused a considerable environmental and health effect, in addition to taking large area from landfills. The second problem was existed in tire pyrolysis plant which faced a lot of environmental and process problems which are the plant doesn't meet environmental standards, unskilled workers, doesn't investigate a further process for the by-product produced prom the pyrolysis.

Any process in the whole world has two aspects which are advantages and disadvantages. For the pyrolysis process, these aspects are given in Table 1.

Table 1: Advantages and disadvantages of pyrolysis.

Advantages	Disadvantages
Remove usable tires from landfill areas	Hard to establish a market for the pyrolysis process
Turn waste into energy	Some tire pyrolysis plants may fail to meet environmental standards, resulting to close the plant.
Produce three valuable fuels	Different product yields because of different tire composition materials.
Further processing for the pyrolysis oil (distillation and desulfurization) turns it into diesel fuel which is used for vehicles.	-
Meet energy demand for the country which used pyrolysis process.	-

1.3. Factors effect on the Pyrolysis Process

Important parameters affect the pyrolysis process directly, and these parameters will be mentioned below in detail.

1.3.1. Pyrolysis Temperature

Pyrolysis temperature features have a significant impact on the tire pyrolysis items. Tire pyrolysis temperatures range is between (400-800) °C, as reported in (Canon et al. 2018) study and shown in Figure 2. The end pyrolysis products of this method are (tire pyrolysis oil, flue gases, and pyrolysis carbon) which changes as the temperature changes. It has been reported that the high-temperature trend to tire pyrolysis oil production from low to medium pyrolysis temperature trend to flue gasses production. Pyrolysis is carried out through the (fast or slow) pyrolysis operation. Fast pyrolysis carried with a heating rate of around 1000 °C/s, short residence time around (3 seconds) in addition to the quick extinguishing of the vaporous items. The characteristics of this operation cause a negligible auxiliary response and, in turn, lead to a high yield of tire pyrolysis oil.

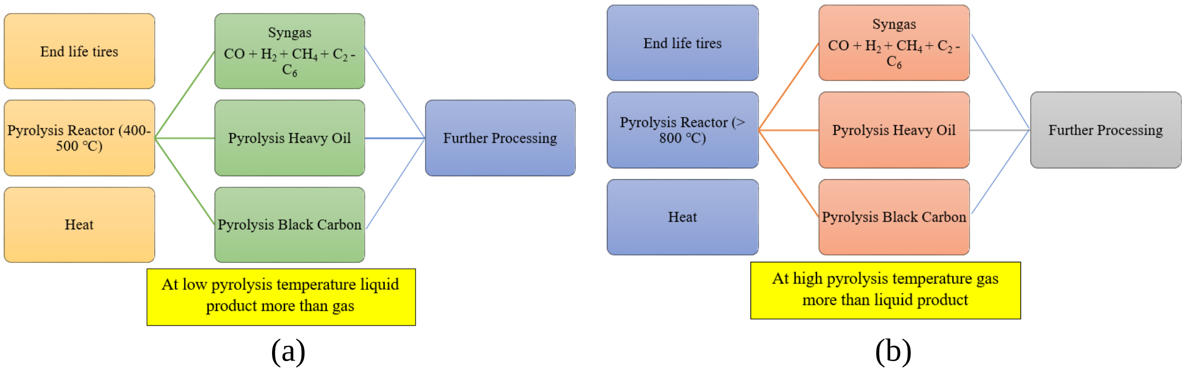


Figure 2. Schematic presentation of a (a) low and (b) high pyrolysis temperature (Hoang et al. 2020).

1.3.2. Pyrolysis Particle Size

Essentially, the impact of molecule measure extending from (10–25) cm^3 was considered by (Aziz et al. 2018). They recorded an increment within the tire pyrolysis oil from (40% at 10 cm^3) to (42% at 15 cm^3), which is the greatest, and over this particle size measure, the pyrolysis oil percentage yield started to reduce. However, an increment within the tire pyrolysis black carbon yields.

All things considered, as the particle size molecule estimated to expand from (2 to 10) mm, the flue gases yield relentlessly diminished as the pyrolysis black carbon increased (Iraola-Arregui et al. 2018). This phenomenon happens due to low thermochemical conductivity and less revealed surface zone of feedstock.

1.4. Work Motivation

This work motivated for the following reasons; low bulk density for the tires, tires cannot be separated by itself or melted because it composes of a thermoset polymer, health and environmental pollution problems when it exposes to open burning, produce a new renewable fuel with high calorific value, reduce the depletion of organic carbon from the natural resource, and produce local industrial briquette carbon fuel to reduce the production cost for the local factories and increase their income and profits.

The main goal of this work is to investigate a technology to produce high energy fuel from waste tire sources. This work solved environmental and health problems for two pyrolysis plants, one of them located in Aqaba and the other located in Um-Alresas. Moreover, this work also eliminates a huge stream of disposable tires from landfill areas by producing industrial briquette carbon fuel after pyrolysis process.

2. Relationship between Past and this Work

Tire pyrolysis product yields for the last 15 years have been studied and reported in Table 2. The pyrolysis oil, pyrolysis black carbon, and flue gas yields are affected by several factors as discussed by the detail in this section and which are pyrolysis reactor type, pyrolysis temperature, particle size, heating rate, composition, and type of tire, if the catalyst used or not in the pyrolysis process, type of catalyst.

Reactor type and pyrolysis temperature have the highest effect on the pyrolysis product yields, which is studied and reported that the pyrolysis oil yield ranged between (31 – 63) percent with a mean yield of 45 %. Pyrolysis flue gases yield ranged between (9 – 49) % with a mean yield of 20.3 %, and the pyrolysis black carbon ranged between (2.5 – 55) percent with a mean yield of 34.2 %. It is noticed that researchers on the pyrolysis process did most studies. They agreed that technically, environmentally, and economically, the pyrolysis temperature ranged between (400-500) °C, and their product yields were very close even if the conditions slightly varied from one process to another.

The 63% pyrolysis oil yield reported by (Chouaya, et al, 2018) was because of adopting conditions for operation in laboratory and not industrial scale, and after studying other articles, the same comment is for pyrolysis black carbon and pyrolysis flue gases. Generally, suppose the right operating conditions will be applied to the pyrolysis process, deciding the higher product yield needed from the process, pyrolysis oil or pyrolysis black carbon. In that case, the product yield will be very close to each other for any pyrolysis industry.

Table 2: Describes several pyrolysis reactor types used, pyrolysis temperature, and the products yields, which obtained from studies.

Reactor Type	Temperature ℃	Pyrolysis Oil %	Flue Gases %	Pyrolysis Carbon %	Ref.
Not reported	600	40.72	12.12	38.25	(Neto et al. 2019)
RKR	550	43.7	21.7	34.5	(Yazdani et al, 2019)
Vacuum Reactor	550	47.1	16	36.9	(Zhang, et al, 2008)
FBR	750	41.4	12.8	45.8	(Januszewicz, et al, 2020b)
Lab-scale FBR	400	43	10	55	Tan, et al. (2018)
	500	48	23	33	
	600	38	40	33	
	700	40	36	34	
Single-step batch reactor	550	43	11	45	Singh et al. (2018)
	600	45	10	42	
	650	53	9	38	
	700	49	12	37	
Not reported	500	45	10	35	Abdallah et al. (2020)
Continuous auger reactor	550	42.6	16.9	40.5	Martínez et al. (2019)
Not reported	500	45	30	25	Kordoghli et al. (2017)
Batch-reactor	450	40.7	12.5	35.1	Tian, et al, (2021)
FBR	500	32	41	27	
Atmospheric reactor	450	43	13.1	43.9	Li et al. (2005)
CSBR	500	63.2	3.1	33.7	Arabiourrutia, et al, (2007)
FBR	400	38.8	27.2	34	Banar et al. (2012)
	400	31.1	33.8	35.1	
CFBR	500	50	15.1	30	Dai X et al. (2013)
CFBR	500	40.1	10	45	
FBR	400	42	14	44	Aziz, et al. (2018)
SSR	550	37.2	30.5	30	Canon, et al. (2018)
FBR	450	42	10	45	Arabiourrutia et al. (2020)
CVD	600	34.4	16.3	48.5	Osayi et al. (2018)
BPR	750	63.5	10	28.5	(Chouaya, et al, 2018)
FBR	450	45.2	20.4	37.5	Singh et al. (2018)
FBR	400	62.8	11.2	26	Raj et al. (2013)
FBR	550	38	Not reported	Not reported	Mkhize, et al. (2016)
Auger	550	42.6	16.9	40.5	Xu, et al. (2018a)
FBR	475	46.6	35.7	17.7	Mkhize, et al. (2019)
BFBR	475	50	35.4	14.6	
CSBR	475	58.2	35.9	5.9	
Moving Screw-Bed	550	55	49	2.5	Tian et al. (2021)

This work parades a new disposable tire management as shown in Figure 3 to implement instead of the management already applied by ASEZA and Ministry of the Environment which faces environmental and social problems.

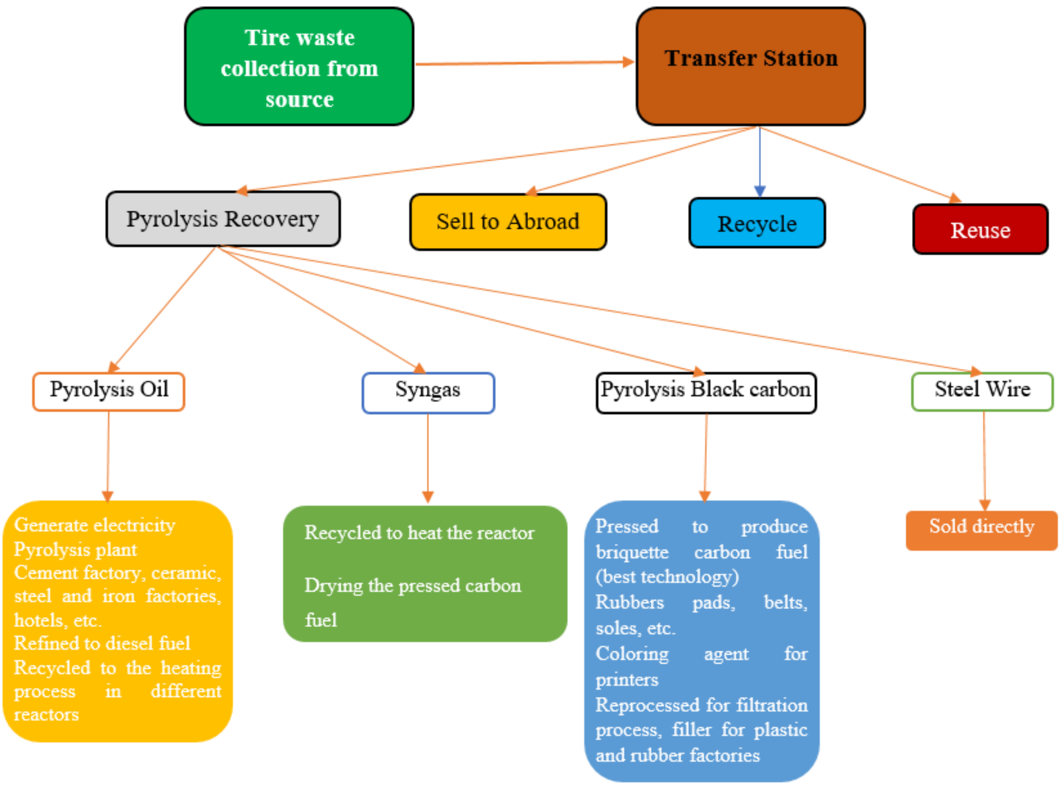


Figure 3. Work detailed management.

3. Experimental Design and Methodology

This section presents the experimental procedure work and shows the technology obtained to produce the fuel which is made from pyrolysis black carbon takes from tire pyrolysis plant.

3.1. Tire Pyrolysis Operation

Tire pyrolysis plant reactors classify as batch, semi-continuous and continuous operations (Qureshi et al. 2018), this work used a continuous reactor, and this type of reactors works for 24 hours with automatic feeding and discharging, and which work simultaneously. The working process is displayed as follows:

1. **Tire waste collection**; any type and size of tire waste.
2. **Shred the tires**; this step needs a complete and single automatic shredding system, which transfers the big tire into small and easy feeding shredded size almost 10 cm

and needs to be connected directly to the reactor feeding system for easier and safer transfer.

3. **Feeding**; shredded tires are fed to the reactor by a suitable feeding process.
4. **Continues pyrolysis and heating process**; the heating process by suitable fuel, the best fuel for such process is pyrolysis oil or industrial briquette carbon fuel or both but in the tire pyrolysis plant located in Aqaba diesel fuel used which does not make sense. After the heating process, the reactor will fully rotate by 360 ° for a uniform heating system. As the temperature starts to rise more than 300 °C, the tires transfer into gas oil.
5. **Cooling system**; oil flow gas will pass by three condensing systems. Firstly, it cools with water to transfer gas into a liquid and collect it in the specified oil tank. After that, the non-condensable gas collected in oil storage tanks will return to the reactor for heating, refined, or collecting for other purposes.
6. **Desulfurization and de-dusting system is** removing the dust and sulfur from the combustible gas to prevent the corrosion of the reactor.
7. **Discharge system**: there is a slag discharge system for the black carbon powder and steel produced as residues from the process.
8. **Cooling tower**: recycling water for the whole process.

Figure 4. Manifold, heavy oil tank, condenser system, oil storage tanks and water seal.

The rest parts of the tire pyrolysis plant shown in Figure 4, which includes.

- **Manifold**: receives the oil gas from the reactor and separates the heavy oil from the light one.
- **Heavy oil tank**: includes auto heavy oil pump and collects the heavy oil from the manifold.
- **Condenser**: which converts oil mixed with gas into liquid oil fuel. This part is significant for the pyrolysis oil yield.
- **Oil storage tanks**: collecting unusable pyrolysis oil gas, which can be used to heat the reactor or refined.
- **Waster seal**: is desulfurization and de-dusting process for the combustible gas.

Pyrolysis products yield conditions depending on the desired outputs which the plant needs. Generally, if pyrolysis oil is the most critical factor, high removal of products from the reaction area and high heating rate will be required (Ahmed, et al, 2018).

Pyrolysis flue gases mainly consist of CO, CO_2, H, and light hydrocarbons with a calorific value of almost 32 MJ/kg, which can heat the pyrolysis reactor and electricity or other heat generation applications.

Steel scrub which obtained from pyrolysis process analyzed in “Saba Tire Recycling Plant.” This steel scrub contains several precious elements, as shown in Figure 5.

Figure 5. Steel wire scrub analysis and testing device.

3.2. Industrial Briquette Carbon Fuel Preparation

Pyrolysis black carbon powder obtained from two tire pyrolysis plants, one of them located in Aqaba, namely Renewable and Alternative Green Energy Industry and the other plant located in Um-Alresas, namely Saba Tire Recycling Industry as shown in the Figure 6.

Pyrolysis black carbon residue comes after cleaning of disposable waste tires, shredding, and pulverizing it thoroughly by the plant. These plants are not dealing with this powder safely, making this component a big environmental and health problem issue. Pyrolysis black carbon powder is obtained from the plant in a black plastic bag and closes tightly to prevent the volatile substance from going out and damaging the work environment.

Figure 6. A sample of pyrolysis black carbon after pyrolysis process and before treatment.

3.2.1. Binding Material

When producing industrial pyrolysis black carbon briquettes, it is essential to know that some visible effects such as smoke and odor are not wanted. Starch was the best binding material used in this process because of its availability, ease of use, and inexpensive, organic material. In addition, it can be safely processed. As mentioned in the (Borowski, et al, 2017) study, any starch used does not have any side effects on the calorific value of the pyrolysis black carbon, which is the most important factor and its toughness, ash, fixed carbon, and the volatile components. Starch cannot be added as it (powder material) needs to be processed first. However, sawdust and paper are also have been tested but not chemically analyzed as starch. Physically sawdust and paper are successfully bound to pyrolysis black carbon but by adding water plus starch. Figure 7 shows the experiment done by adding starch + paper + sawdust in the presence of hot water.

Figure 7. Binding materials used for experiment.

3.2.2. Other additives

Some binding materials need to be mixed with water to make it work effectively. Dry bindings such as starch, paper, and sawdust are ineffective binding materials without adding water. Several processing steps can be used when water is added to the binding material, which is all experienced in this work and listed below.

1. Add starch powder to the pyrolysis black carbon powder, then add room temperature water.
2. Add starch + paper + sawdust to the pyrolysis black carbon powder, then add room temperature water.
3. Add Starch powder to the pyrolysis black carbon powder, then add boiled water.
4. Add starch + paper + sawdust to the pyrolysis black carbon powder, then add boiled water.
5. Mix starch with room temperature water, then add it to the pyrolysis black carbon powder.
6. Mix starch with room temperature water, add it to the pyrolysis black carbon powder and add sawdust and paper.
7. Mix starch with room temperature water, then boil it to convert the mixture into sticky material. After that, add pyrolysis black carbon powder.
8. Mix starch with boiled water, then add it to the pyrolysis black carbon powder.
9. Mix starch with boiled water, add it to the pyrolysis black carbon powder and add sawdust and paper.

All these suggestions worked in the Al-Hussein Bin Talal laboratory, resulting in adding 0.03 kg starch to the 1 L room temperature water then making it boil and converting it into effective sticky material as shown in Figure 8. However, other worked suggestions also succeed but do not meet economic, high effectiveness, and easy process goals. Therefore, in this situation, other additives to the starch binding material needed are heat and water.

Figure 8. Pressed pyrolysis black carbon.

This worked process, called starch gelatinization, as shown in Figure 9, distributes the starch intermolecular bonds and creates sites for hydrogen bonds to attach additional water molecules, making the starch soluble in the cold-water (Pei Xu et al. 2021). When the starch turns into a sticky and transparent material, the process is completed and is ready to add to the pyrolysis black carbon powder to make the briquettes.

Figure 9. Starch is added to the room temperature water and start stirring it to dissolve before heating process.

3.3. Mixing process

After ending the gelatinizing starch process, the glue is added to the pyrolytic black carbon powder and mixed well by using a mixer, which is in tire pyrolysis industry in Aqaba before pressing, as shown in Figure 10.

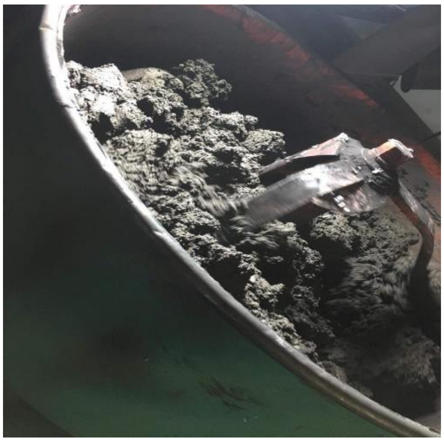


Figure 10. Mixing pyrolytic black carbon with gelatinized starch in Aqaba's tire pyrolysis industry.

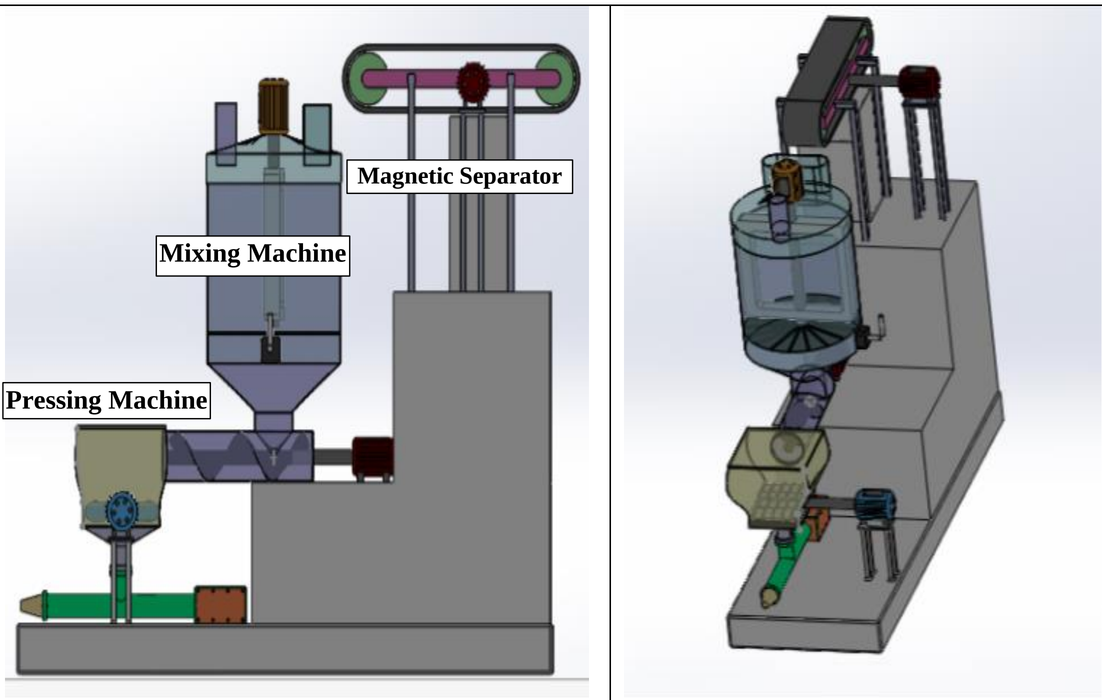
3.4. Briquetting Press

Briquetting press is a process that converts waste into usable solid fuel such as industrial briquette carbon fuel, which recovers from end life tires. The higher the briquette presser, the means the combustion process will take a longer time.

3.4.1. Briquetting Press Design

There are several briquette pressing machines available today with varying performance and efficiency. It is almost the same as a meat grinder machine; an excellent pressing machine needs to achieve high industrial briquette carbon fuel efficiency. This work designed a briquette pressing machine by using Computer Aided Design CAD with the following components as shown in Figure 11.

Several studies mentioned a good briquette construction model, which helps this work to succeed some of these studies are Kowalski et al. (2018), which presented mechanical press machine, ĽubomírŠooš et al. (2019) presented a screw press machine, and Kayode and Gideon (2019) which presented a hydraulic waste briquette machine. The pressing machine presented in Kowalski et al. (2018) is an excellent choice to follow but requires some modifications. The construction of the briquette machine was robust and compact design, with high productivity and low sensibility to the batch changes. This work presented a good and suitable version of production for any raw materials but the type of raw material used affects the pressing machine efficiency and product quality.



(A) (B)

Figure 11. A and B are industrial briquette carbon fuel pressing machines.

After the pressing and drying process, the pyrolytic black carbon powder converted into industrial briquette carbon fuel successfully, which means the waste converted into fuel as shown in Figure 12.

(A) (B)

Figure 12. A and B are industrial briquettes carbon fuel.

The different shapes and size of each briquette worked in this research because of different pressing machines used. The industrial briquette carbon shown in the Figure 8 pressed by mould in AHU laboratory and the pressed fuel in Figure 12(A) pressed by machine located in tire pyrolysis industry in Aqaba, and the rest part (B) shown the briquettes pressed in Um-Alresas industry.

3.5. Ultimate and Proximate Analysis

The ultimate analysis was applied to determine the chemical composition of industrial briquette carbon fuel. On the other hand, the proximate analysis obtains calorific value, volatile matter, ash, carbon, and moisture content for the sample.

3.5.1. Elemental Analysis

The elemental analysis applies to determine the elemental composition of the industrial briquette carbon fuel such as oxygen, hydrogen, nitrogen, carbon, and sulfur. ASTM D5373 method applies to determine the hydrogen, carbon, nitrogen, and sulfur elements. Oxygen is determined by using the difference in percentage as shown in **equation (1)**.

Oxygen (O_2) = 100 – Carbon (C) – Hydrogen (H) – Nitrogen (N) – Sulfur (S) . . . . . . **(1)**

Moreover, moisture content is calculated based on the difference between the weighted sample before and after heating, as shown in **equation (2)**.

$$\text{Moisture content in analyzed sample (\%)} = \frac{A-B}{A} \times 100 \qquad \text{. . . . . (2)}$$

where A is the weight sample before heating (g) and B is the determine weight sample after heating (g).

Now the data are ready to calculate the ash content by using **equation (3)**.

$$\text{Ash content in analyzed sample (\%)} = \frac{C-D}{E} \times 100 \qquad \text{. . . . . (3)}$$

where *C* is the determined weight of capsule, ash, and cover (g), *D*: determine weight of capsule and cover (g), and *E*: determine total weight of analyzed sample (g).

$$\text{Weight loss (\%)} = \frac{A-B}{A} \times 100 \qquad \text{. . . . . (4)}$$

And by using **Equation (2)** volatile matter determined as follows:

Volatile matter content (%) = weight loss (%) – moisture content (%) . . . . . **(5)**

Fixed carbon = 100 – moisture content – volatile matter – ash content . . . . **(6)**

3.6. Experimental Work Summary

Several steps follow to make briquettes carbon fuel from tire pyrolytic carbon powder. First, it is essential to note that many experiments before adopting this manufacturing process, described in Figure 13.

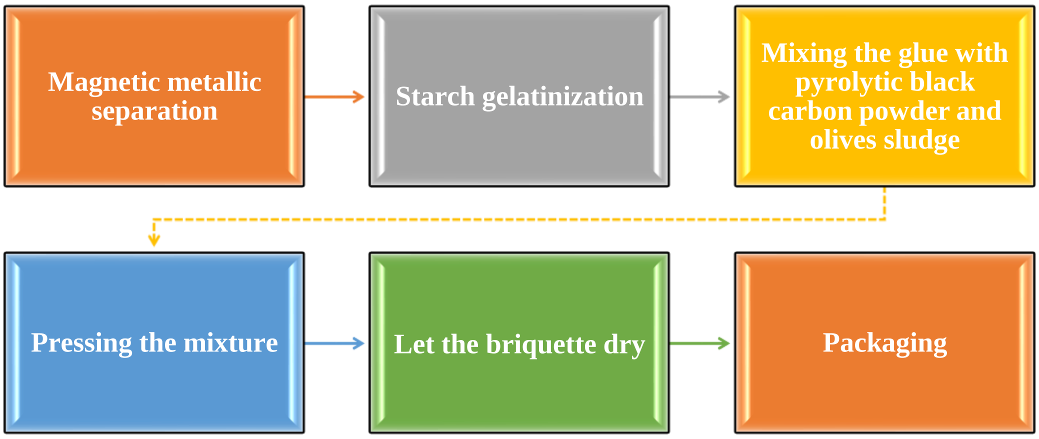


Figure 13. Summary of manufactured process for the industrial briquette carbon fuel.

4. Experimental Results and Data Collection

In this section, results obtained from several official departments such as Royal Scientific Society, Al-Hussein Bin Talal laboratory, Lafarge ARC laboratory, Saba Recycling Tire Plant laboratory introduce the properties of industrial briquette carbon fuel manufactured in this thesis work, steel wire, and pyrolytic oil products which pulverized in Saba Recycling Tire Plant. Following the discussion and comparison of the produced fuel from waste and the other natural industrial solid fuel properties from previous studies.

4.1. Mineral Composition of Steel Wire Scrub

The chemical and physical properties analyzed in this work by Saba Tire Recycling Plant laboratory are shown in Table 3. Steel wire scrub, produced from the pyrolysis process as residue, can be sold directly to its market. The data in Table 4 is accurate but slightly varied according to the tire production plant.

Table 3: Mineral composition of steel wire scrub analyzed in this work.

Element	Content %	Limit
Fe	99.20 ± 0.315	96 - 100
Ti	0.17 ± 0.027	----
Mn	0.59 ± 0.028	0.3 – 0.6
Ni	0.04 ± 0.011	0 – 0.3

Table 4: Physical properties of steel wire scrub analyzed in this work.

Physical statement	Solid wire
Color	Grey / black
Odor	No odor
Density kg/m3	295
Solubility in water	Insoluble
Melting point oC	1400 °C – 1700 °C

4.2. Industrial Briquette Carbon Fuel Properties

Waste to energy, from usable tires to industrial briquette carbon fuel, by this technology the waste can make money. The first environmental problem was throwing the usable tires into landfills without processing, and the second problem was not dealing with pyrolytic black carbon after pulverizing. Pressing this by-product with suitable and organic binge materials makes this fuel valuable to its consumers, such as cement factories. The briquettes made from pyrolytic black carbon are slightly more complicated than making it from natural charcoal or coal because of its oil content, which makes this powder need a binding material to press. Further, mixing this binder and pyrolytic black carbon is the secret of making high-quality briquette fuel. The pyrolytic black carbon has a high calorific value because of its high carbon content, fixed carbon, low ash, and Sulfur content, making this fuel determined as high-quality briquette fuel.

Moisture and carbon content are considered as the main parameters which determine industrial briquette carbon fuel quality. Lower moisture content and higher carbon content inside the fuel means a higher calorific value. It is important to note that the industrial briquette carbon fuel burned without any sparks or smoke. High calorific value analyzed by RSS and reported in Table 5 which is 28 MJ/kg, and if this value compares with several commercial fuels, it will be higher in calorific value, lower in price, and renewable option, as well as this fuel, protect the trees from cutting around the world. Table 6 describes the physicochemical properties of industrial briquette carbon fuel.

The quality of the industrial briquette carbon fuel assessed of the bases of their physiochemical condition revealed that the total energy needed to ignite the fuel up to its pyrolytic temperature depends on moisture content, which affects internal fuel temperature due to the endothermic evaporation process. High carbon content makes this fuel contain on high calorific value compared to other commercial carbon fuels. It is challenging to ignite industrial briquette carbon fuel, but when it ignites, it is like a fire that never goes out and keeps burning for a long time.

Five samples were analyzed in RSS, sample #4 is pyrolytic oil, and the rest samples are industrial briquette carbon fuel. The raw material is taken from two industries, located in Aqaba and the other in Um-Alresas. The raw material for sample #4 and #5 are taken from Aqaba's industry and #1, #2 and #3 taken from Um-Alresas industry.

In the Table 5 each sample worked in this thesis displayed and discussed how it pressed. The calorific values are the most important feature for the industrial briquette carbon fuel analyzed in RSS laboratories and listed in Table 6.

Table 5: Calorific values for the analyzed samples by RSS.

Sample #	**1**	**2**	**3**	**4**	**5**
Description	C + starch pressed by machine	C + starch + CaCO3 pressed by machine	C + starch + sludge pressed by machine	Pyrolytic oil	C + starch pressed by mould
Calorific Value Mg/Kg	23.4	12.0	23.57	40.75	28.14

Table 6: Industrial briquette carbon fuel physiochemical properties.

Type of Test	**According to**	**This work sample 5**	**This work sample 3**	**Pyrolysis char (Taleb et al. 202)**	**Commercial CB (Yao et al. 2017)**	**Coal (Iluk et al. 2019)**
Proximate Analysis						
Fixed carbon	Calculated	84.47	53.7	21.51	-	-
VM %	ASTM D 3157-07	0.69	24.83	64.41	21.4	25.5
Ash %	ASTM D 3174-02	13.52	16.76	13.78	32.5	11.8
Ultimate Analysis						
Moisture %	ASTM D 3173-11	1.32	4.71	2.26	-	19.1
C %	ASTM D 5373	78.98	67.15	63.6	56.19	53.2
S%	ASTM D 5373	4.82	3.87	3.31	-	1.0
H%	ASTM D 5373	1.37	2.64	6.76	-	3.1
N%	ASTM D 5373	0.83	1.33	0.97	-	0.8
Calorific Value						
GCV MJ/kg	ASTM D 240-19	28.14	23.57	23.02	21.56	20.7

Note: the TGA graph for sample 5 and sample 3 respectively are presented in Figures A1 and A2 in appendix.

- *Carbon content*: this component is responsible for energy in the fuel and in this work the carbon content is high and higher than other fuel sources which compared with. The carbon content for sample #5 is 78.98 % and for sample #3 is 67.15, for the other comparable fuels which are pyrolysis char, commercial CB, and coal the carbon content was 63.6 %, 56.19%, and 53.2% respectively.

- *Moisture content*: this component is the lowest in this work 1.32 % for sample #5 and for sample #3 is 4.71 and which consider a high value. Moreover, for the other comparable fuels which are pyrolysis char and coal the moisture content was 2.26% and 19.1% respectively. Moisture content decrease the calorific value in the fuel, so that, for good energy fuel the moisture content must be low as it in sample #5 worked in this thesis.
- *Calorific value*: is the most important component and the main goal for this work, it must be high enough to consider this fuel as valuable and favorable to industries. In this work sample #5 and sample #3 contain higher calorific value than the other fuels. Calorific value for sample #5 is 28.14 MJ/kg and for sample #3 23.57 MJ/kg and these values are higher than the other comparable fuels; pyrolysis char, commercial CB, and coal and their calorific value were (23.01, 21.56, and 20.7) MJ/kg respectively.

4.2.1. Project Information

This project aims to establish an industrial briquette carbon fuel as a part of the tire pyrolysis industry to convert waste tires into valuable fuel products. This project will solve two main problems exiting in Jordan. The first problem is removing the usable tire waste from landfills using the best available technology known by pyrolysis. The second problem after the pyrolysis process is that if the pyrolysis black carbon is not manufactured, it will cause severe health and environmental problems. Though, by establishing this industry, these two problems will be solved correctly.

4.2.2. Economic environment in the short and medium term

The risk analysis carried out by BMI indicates that Jordan’s political and economic risks in the short and medium-term are better than the general average for the world and the Middle East, and the country and operational risks were within acceptable levels as shown in Table A1 in appendix. The expectations of international institutions also indicate the achievement of acceptable growth rates in economic indicators and foreign trade, as shown in Table A2 in appendix, except for a contentious increase in internal and external indebtedness.

The pyrolysis tire recovery will establish with 9,000 tons/year of tires design capacity. In order to reach the design capacity, the land will rent from ASEZA. Buildings with an area of 800 m^2 will construct, and stores with an area of 500 m^2.

Table 7 will presents the project material resource estimated after studying the Jordanian market.

Table 7: Project material resource.

Statement	Unit	Price (JD)	Value (JD)
Buildings	800 m2	200/m2	160,000
Stores	500 m2	150/m2	75,000
Equipment's	-	-	500,000
Transport	3	25,000	75,000
Technology	-	10,000	10,000
Laborites and other requirements	-	-	10,000
Total	**830,000 JD**		

The human resource required for the briquette project industry list in Table 8 includes the total number of employees, 12 employees, and the total salary required for them is about 67,920 JD/year. The annual salary distributed between operational and administrative employees is 31,920 JD/year and 36,000 JD/year.

Table 8: Human resource required for the project.

Occupation	# of Employees	Salary (JD/month)	Annual Salary	Operational Annual Salary	Administrative Annual Salary
General Director	1	1,000	12,000	-	12,000
Supervisors and Engineers	2	650	15,600	15,600	-
Technicians	2	400	9,600	9,600	-
Administrative, Accounting, Marketing, and Procurement	5	400	24,000	-	24,000
Workers	2	280	6,720	6,720	-
Total	**12**	**-**	**67,920**	**31,920**	**36,000**

The following Table 9 shows the project schedule for implementing the project, which is 18 months.

Table 9: Project schedule.

Statement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Studies	■	■																
Approvals, licensing, and registrations			■	■	■	■												
Construction phase					■	■	■	■	■	■	■							
Preparation and furnishing of machines and equipment's											■	■	■	■	■			

Start of experimental production																		
Total duration	**18 months**																	

This fuel is considered alternative and renewable for fossil fuels because it is not adding CO_2 to the atmosphere when it burns in the reactors by other industries. The CO_2 in the atmosphere is only recycled. This work is very similar to biofuels, also considered renewable energy from waste to energy section. An environmental benefit from converting usable tires waste into industrial briquette carbon fuel is the reduction of adding more amounts of CO_2 into the atmosphere, which is a GHG that comes from non-renewable resources such as fossil fuels.

5. Conclusion

- The major findings of this work concluded below;

1. The most important findings in this work is the calorific value and which consider very high 28.17 MJ/kg compared with other fuels.
2. The total profits for tire pyrolysis recovery plant is about 1,085 M JDs.
3. The total profits for the industrial briquette carbon fuel plant is about 622,490.5 JDs.
4. This fuel is considered alternative and renewable for fossil fuels because it is not adding CO_2 to the atmosphere when it burns in the reactors by other industries. The CO_2 in the atmosphere is only recycled.

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- **Conflicts of Interest**: The authors declare no conflict of interest.

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Appendix A

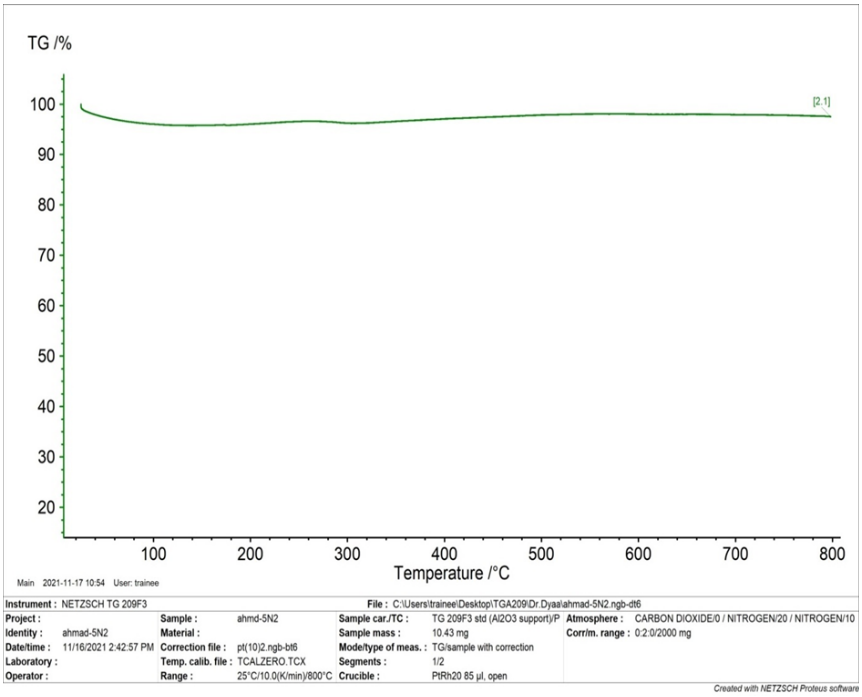

Figure A1. TGA analysis graph for sample 5

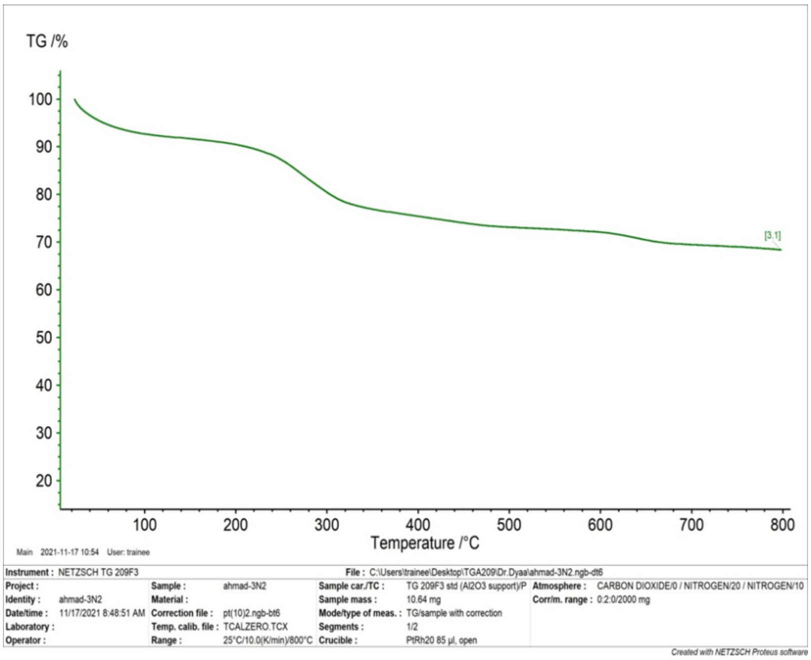

Figure A2. TGA Analysis Graph for Sample 3.

Table A1 Economic Environment in the Short- and Medium-term Assessment (Economy and Country Risk, IHS, 9/15/2016)

	Short-term		Long-term		Operational Risk	State Risk
	Politician	Economic	Politician	Economic		
Jordan	63.1	39.2	66.6	46.2	58.7	55.4
Turkey	60.2	49.4	58.4	56.9	55.9	56.1
Egypt	53.3	45.0	52.4	48.7	42.9	47.5
Lebanon	45.8	54.0	55.4	53.5	44.2	49.5
Gaza	33.1	38.1	32.2	36.5	32.5	34.3
Syria	22.9	24.4	22.4	23.6	29.3	26.1
Average Area	49.4	46.9	51.2	48.7	46.6	48.3
Average World	64.1	50.7	61.3	51.9	49.8	54.6

Table A2 Economic Indicators 2016 – 2020 (Economy and Country Risk, IHS, 9/15/2016)

Indication	2016	2017	2018	2019	2020
GDP growth rate	2.6	2.7	2.8	3.2	3.1
GDP (US $ billion)	39.6	42.1	44.8	47.8	50.9
Population (million)	9.8	10.1	10.4	10.7	11.0
Consumer Price Index (% change)	-0.7	1.8	3.3	4.0	3.2
Exports (US $ billion)	7.3	7.6	8.2	8.8	9.6
Imports (US $ billion)	18.3	19.2	20.1	21.3	22.8
Foreign Direct Investment, net (US $ billion)	1.5	1.5	1.6	1.6	1.7
Foreign Direct Investment, net (% of GDP)	3.7	3.7	3.6	3.4	3.3
Foreign exchange reserves (US $ billion)	13.9	14.9	15.7	16.8	17.7
Total external debt (US $ billion)	24.4	27.8	30.7	33.7	36.0
Total external debt (% of GDP)	61.6	66.0	68.6	70.4	70.6
Total external debt (% of foreign exchange earnings)	127.3	138.3	143.6	147.5	147.8