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RESEARCH ARTICLE

Access to Leading Unit Design with Suitable Operating Conditions for the Production of Carbon Black-type SRF

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ABSTRACT

In this research, technological knowledge for the production of carbon black type semi-reinforcing furnace (SRF) was achieved by designing and building an experimental unit consisting of a furnace, cooling tower, cyclone, filtration and separation unit, and drying and physical treatment unit. Gas oil and fuel oil were used as raw materials in the production of carbon black-type SRF. Partial combustion technology was adopted to meet its technical requirements locally. Economically, partial combustion and oxidative pyrolysis have become mainstream methods. These methods involve the use of hydrocarbons that play a dual role; in addition to being a source of heat, they also help in the production of carbon black. Carbon black is primarily used as a filler or reinforcing agent in various rubber mixtures, especially in the tire and other rubber industries. It also serves as a black pigment in printing inks, surface coatings, paper, plastics, and other applications. The raw materials used in this research produced a good yield and exhibited similar properties to the commercial sample when appropriate operating conditions were selected. The production of carbon black from gas oil was successfully distinguished in this pilot plant, providing better specifications and a more straightforward production method than fuel oil.

Keywords: Carbon black type SRF, Fuel oil, Gas oil, Partial combustion, Pilot plant

Introduction

Carbon black is an engineered material produced from highly controlled partial combustion or thermal decomposition of hydrocarbons, primarily composed of >98 % elemental carbon.[1] This number may vary depending on the production process and the desired application. Carbon black may be doped with elements such as oxygen, nitrogen, or sulfur to enhance the solubility, dispersion, or binding properties of the material.[2,3] The designation of different kinds of carbon black refers to the different processes used in their manufacture. These processes include acetylene black, channel black, furnace black, lampblack, and thermal black.[4,5] In the manufacturing process, carbon black particles are formed that range from 10 nm to approximately 500 nm in size. These fuse into chain-like aggregates, which define the structure of individual carbon black grades. Applying the terminology of the International Organization for Standardization's (ISO) Technical Specification 80004-1 of 2015, carbon black is considered a nanostructured material (i.e., a material having internal or surface structure in the nanoscale).[6] The principal uses of carbon black are as a reinforcing agent in rubber compounds, especially tires, and as a black

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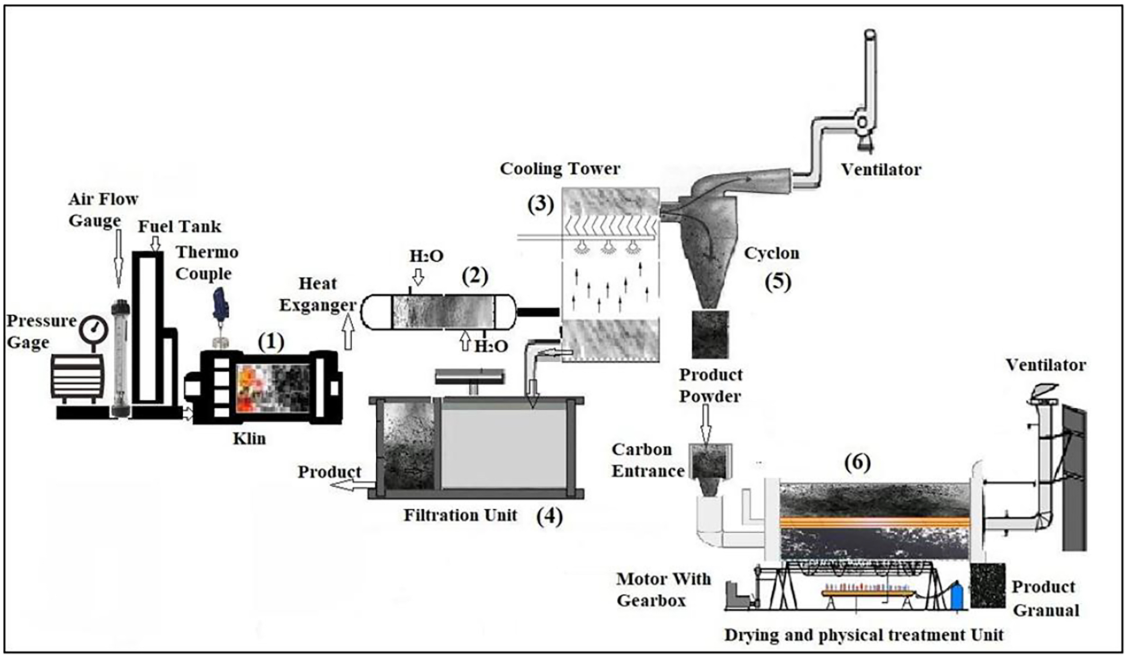

Scheme 1. Pilot plant for the production of carbon black-type SRF.

pigment in printing inks, surface coatings, paper, and plastics.[7,8]

Carbon blacks are different from other bulk carbon materials like diamond, graphite, cokes, and charcoal because they are made of colloidal-sized aggregates with complicated topologies and a quasi-graphitic structure. Being generated from the vapor phase by homogenous nucleation through the thermal decomposition and partial burning of hydrocarbons, they are different from other bulk carbons.[9] The technology that produces carbon black combines cutting-edge process controls and engineering. Its purity differentiates it from soots that are impure by-products of the combustion of coal and oils and the use of diesel fuels. Carbon blacks are typically free of inorganic contaminants and organic residues found in most other forms.[10,11]

The process of producing carbon black involves splitting hydrocarbons into carbon and hydrogen through thermal or thermal-oxidative processes. Economically, thermal-oxidative decomposition is the predominant method, with hydrocarbons serving both as a source of heat and carbon. Every method of producing carbon black relies on heat and decomposition; the arrangement of these stages determines the production process.[1,12] The objective of this study was to prepare carbon black with properties comparable to those found in commercial carbon black, type (semi-reinforcing furnace) SRF. We designed and built a pilot plant experiment by establishing a technical line. Partial combustion, and operation conditions are required to produce active black filler with good characteristics. To achieve this goal, the work was divided into two directions. The first direction involved testing the physical and chemical properties of the prepared carbon samples and then comparing them to the properties of commercial carbon samples. The current work is schematically depicted in Scheme 1.

Practical part (designing and building the pilot plant)

The pilot plant consists of five parts: furnace, cooling tower, cyclone, filtration and separation unit, and drying unit and physical treatment. These parts were connected with groups of equipment, pumping devices, and controlling measurements. Fig. 1 explains the connection work of these parts together and their diameters.

Furnace

The temperature of the furnace was controlled by controlling the fuel and air pumped inside. Raw materials can be pumped either by evaporation of distillate oil or by using an atomizer for heavy oil. Temperature measurement was achieved by a thermocouple. The furnace is connected by a metal tube to a cooling tower. The benefit of this tube is to shorten the distance of passing gases to give

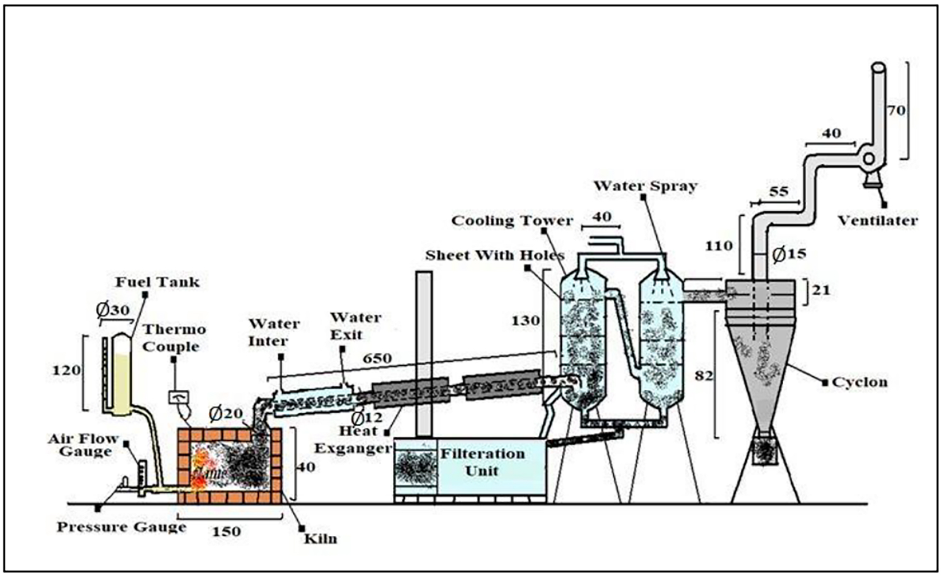

Fig. 1. Designing the pilot plant.

enough time to complete the thermal cracking of raw materials.[13]

Cooling tower

The metal tube is connected to a cooling tower, through which hot gases pass. At the top of the tower, water spray is released, which comes into contact with the gases from the bottom. To ensure better contact between the water, production, and gases, there are three perforated sheets. The process of quenching takes place, which reduces the temperature and stops the reactions. The production is then transferred to a second tower from the top of the first tower, and the same process is repeated. The water is drawn from the bottom of each tower and connected with the same tube to flow into the filtration unit. At the filtration unit, the production is separated from the water.[14]

Cyclone

Combustion production is passed from the upper of the second cooling tower to enter the cyclone (to separate small solid particles), and it is a passage for gases through the cyclone to the exhaust.[15]

Filtration and separation unit

It consists of a circle tank with a diameter of 150 cm and a height of 55 cm, Fig. 2. The last third of the circle basin contains a moving perforated sector

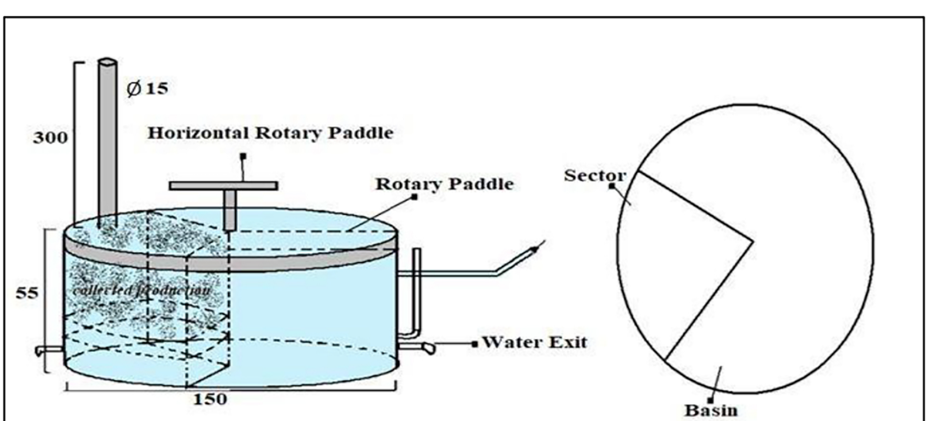

Fig. 2. Filtration unit detail.

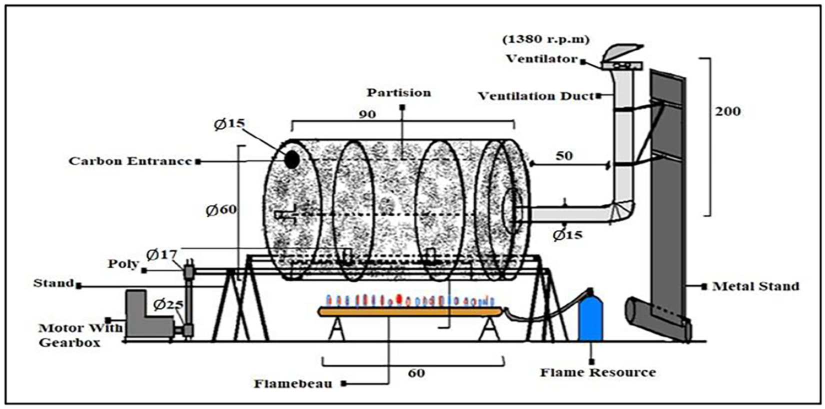

Fig. 3. Drying unit and physical treatment detail.

that can be pulled from the basin. The lower part is connected to a pipe to pass water that comes from the cooling tower and flows into the main basin. The center of the basin is connected with horizontal paddles. It is supplied with a rubber part under a water surface of about 1–2 cm. This paddle moves in continuous rotary motion by using an electric motor. Rotary speed is controlled by using a gearbox. The speed must not be more than (2–3) rotary/minute. The rotary paddle collects floating carbon particles in the moving sector. A piece of cloth can be put on this part as a filter.[15]

Drying unit and physical treatment

The production of carbon black involves a significant amount of water, which makes it difficult to handle due to its low density. This process is considered to be polluting and not economical, especially when it comes to storing, transporting, and manufacturing it. The purpose of this unit is to dry the carbon, increase its density, and convert it into particle form with a higher density.

The drying unit is comprised of a cylindrical metal tank with a diameter of 90 × 60 cm, Fig. 3. Inside the tank, four metal partitions aid in the rotation of the production and ensure homogeneity. The tank is fixed on a base that has two rotary axes, one of which is connected to an electric motor. The gearbox controls the number of rotations per minute. To empty the tank, it can be raised away from its base, or a ventilator can be used. The tank is heated using a suitable horizontal flambeau.[3]

Results and discussion

Operation condition

Controlling the temperature's degree and mixing air with fuel is one of the most important steps to give a suitable yield with good characteristics. These are some practical results that explain the relationship among these variables.[16]

Temperature degree and the ratio of air/fuel

Controlling the temperature and mixing air with fuel is one of the most important steps used to produce a suitable product with good specifications Tables 1 and 2. The kiln temperature and the quality of the production are influenced by the ratio of air to fuel and temperature, respectively. The ratio of volatile materials and physical characteristics, such as tensile strength and hardness, found in rubber samples that contain carbon black products still have an influence. However, increasing the temperature leads to a decrease in yield.[14]

Table 1. The relationship between temperature and air/fuel.

Temperature °C	Average of fuel flow L/H	Average of air flow L/H	Ratio of (fuel-air) weight	Kind of combustion
750	1	20000	1/27.2	Complete
950	2	25000	1/17	Complete
1000	2	23000	1/15.6	Complete
1150	4	25000	1/18.5	Complete

Table 2. The relationship between temperature and the quality and quantity of the production.

Temperature °C	Average of fuel flow L/H	Average of air flow L/H	Ratio of fuel-air	Rubber mixture type SMR62 (Tensile strength test)	Ratio of volatile substances	Yield %
850	5	13500	1/3.5	107	13.8	10.5
1000	8	20000	1/3.4	136	4.1	9.5
1100	5	20000	1/5.4	176	9.8	9.5
1200	6	19000	1/4.3	179	3.8	8
**1200 >	8–9	28000	1/4.2	213	2.3	6
1200 >	7–9	28500	1/4.3	238	2.2	6

** The value of temperature over 1200 °C is not known, because there is no suitable thermocouple in such thermal conditions, so the ratio of air/fuel is only dependent.

Table 3. Granular size of samples before and after physical treatment.

Measured characteristic	Before treatment	After treatment	Commercial sample
Specific gravity	0.8–1.2	0.24–0.37	0.39
Granule size (mm)	Powder less than 0.25	Granule (0.25–2.5)	Granule (0.5–3)

Table 1 shows a correlation between temperature and the air/fuel ratio, which affects the production process. In Table 1, the combustion is complete without obtaining any quantity of production. Table 2 shows that when the ratio is changed, production is affected. The total yield of the process depends on the ratio of air/fuel. The determination of this ratio depends on the kiln temperature; if any decrease or increase in this ratio affects directly the kiln's temperature, then the nature of the production will change, so the yield will change. The reason for that is the increasing temperature that demands burning a lot of fuel. Another carbonization reaction is endothermic and consumes a lot of fuel; this leads to burning additional quantities of fuel to keep the oven's temperature stable.[17]

Physical treatment and drying

Physical treatment improved the production quality and made it easy to deal with. In this process, the production is dried, so its density changes and it is converted from powder form to particle form. Production properties are influenced by this treatment, Table 3. After many experiments, suitable circumstances are used for samples with good physical properties. These circumstances are represented as follows: number of drying unit cycles (3 revolutions/minute), the temperature inside the unit (150–180 °C), and treatment time (3–6 hours), depending on the product's degree of hydration.[18]

Raw materials nature

Gas oil and fuel oil are used as raw materials. Both substances have a good yield and characteristics similar to those of commercial samples. But producing carbon black from gas oil (in this pilot) is better and easier than from fuel oil. The reason for this is that determining the ideal operating conditions for producing carbon black from fuel oil is challenging. Gas oil was used as a raw material, pumped, and burned in kilns by the atomizer to obtain production. When using fuel oil, a heating unit is required to aid in pumping. An atomizer is necessary to prevent carbonization in tubes, which can cause blockages.[12] If the atomizer's pump power exceeds the pilot volume, it can lead to high combustion pressure, causing a break in the kiln and affecting its operation. This, in turn, can weaken the performance of the cooling tower and other units as production exceeds the pilot's capacity. These experiments give encouraging results for production quality and yield when using fuel gas.[13]

Unit's yield

Temperature and production quality typically influence the low yield of carbon black. When the temperature is higher, the yield gets low, and the quality increases. Production energy is calculated depending on the yield and the quantity of fuel consumed in production. Production energy is about 1/2 Kg/h, which equals 3.6 tons/year. Suppose that the unit is working 300 days a year. But when using fuel oil, it found that production energy (at least) is about 7.5–7.0 tonnes per year.[3]

Characteristics of the production

Carbon black samples have different chemical and physical characteristics and influence the rubber mixture.[19] This study aims to obtain production with

Table 4. Rubber mixture (SMR62) composition.

Substances	Chemical formulas or symbols	Weight (kg)
Natural rubber	SMR	100
Active	Zno	5
Active	Stearin	1
Antioxidant	4010 Na	1.5
Antioxidant	H	1
Carbon black	SRF	50
Softeners	Oil	5
Accelerator	Cz	0.8
Accelerator	Dm	0.1
Crosslinking agents	Sulfur	2.2

Table 5. Rubber mixture (SMR62) properties.

Mixture properties	Standard value
Tensile strength	219
Elongation %	516
Hardness A°	62

similar characteristics to commercial sample-type SRF. This comparison is done in two directions. The first is represented by doing tests on physical and chemical properties to produce samples and compare them with commercial samples. The second direction is represented by using produced samples and commercial samples, each one alone, in a certain rubber mixture type (SMR62), then doing some tests on the rubber production and noticing the differences. Tables 4 and 5 show the composition and properties of the rubber mixture type SMR62, respectively.

The BET test and iodine number give information on the surface area of carbon black. These values increase with increasing surface area. The DBP number (dibutyl phthalate) explains why the sample is homogeneous with hydrocarbonic materials.[19] Table 6 and Fig. 4 show the prepared samples outperformed the commercial samples. Table 7 shows the circumstances and properties of the prepared rubber mixture from the pilot plant.

Table 8 shows the operating conditions of prepared samples, including temperature, raw materials, and air/fuel ratio.

Good yields and properties similar to those of the commercial sample were obtained when appropriate operating conditions were determined and used with the raw materials. In addition, carbon black production from gas oil was found to be more efficient and easier than that from fuel oil in this pilot plant, resulting in better specifications, Table 9.

General observation about the pilot plant

In the end, it must explain some objects concerning the plant that require more work to establish a successful industry in terms of technical, economic, and environmental aspects.

Pilot gas production

It's important to consider the quantity of gases, such as CO_2, SO_x, and NO_x, which remain from partial combustion, as their ratio can differ depending on the operating conditions, such as temperature, air/fuel ratio, and materials used. Knowing the ratio of these gases is crucial to understanding the appropriate method of treatment or how to dispose of them safely.[17,20] Despite the importance of knowing the proportions of these gases in the combustion products to determine the treatment method, we postponed such a study and focused on obtaining the product with the required specifications. There will be a complementary study to treat the gases when considering moving the unit to the production level.

Controlling solid materials in combustion

Combustion gases contain a quantity of production that escapes during combustion and cannot be collected using a cyclone. Proper separation techniques require precise scientific study and specialized engineering calculations to manufacture effective separation equipment. This ensures high production with reduced pollution.[21]

Table 6. Characteristic of prepared samples with commercial carbon black.

Test	Sample1	Sample2	Sample3	Commercial carbon black
BET* m^2/g	77.5	118.3	71.9	75.8
Iodine No. mg/g	95.6	98.45	68.8	68.5
PH	7	6.5	6.5	7
Volatile matter	2.2	2.3	3.4	2.5
Ash content	0	0	0	0
DPB No: mc/100g	185	145	240	80

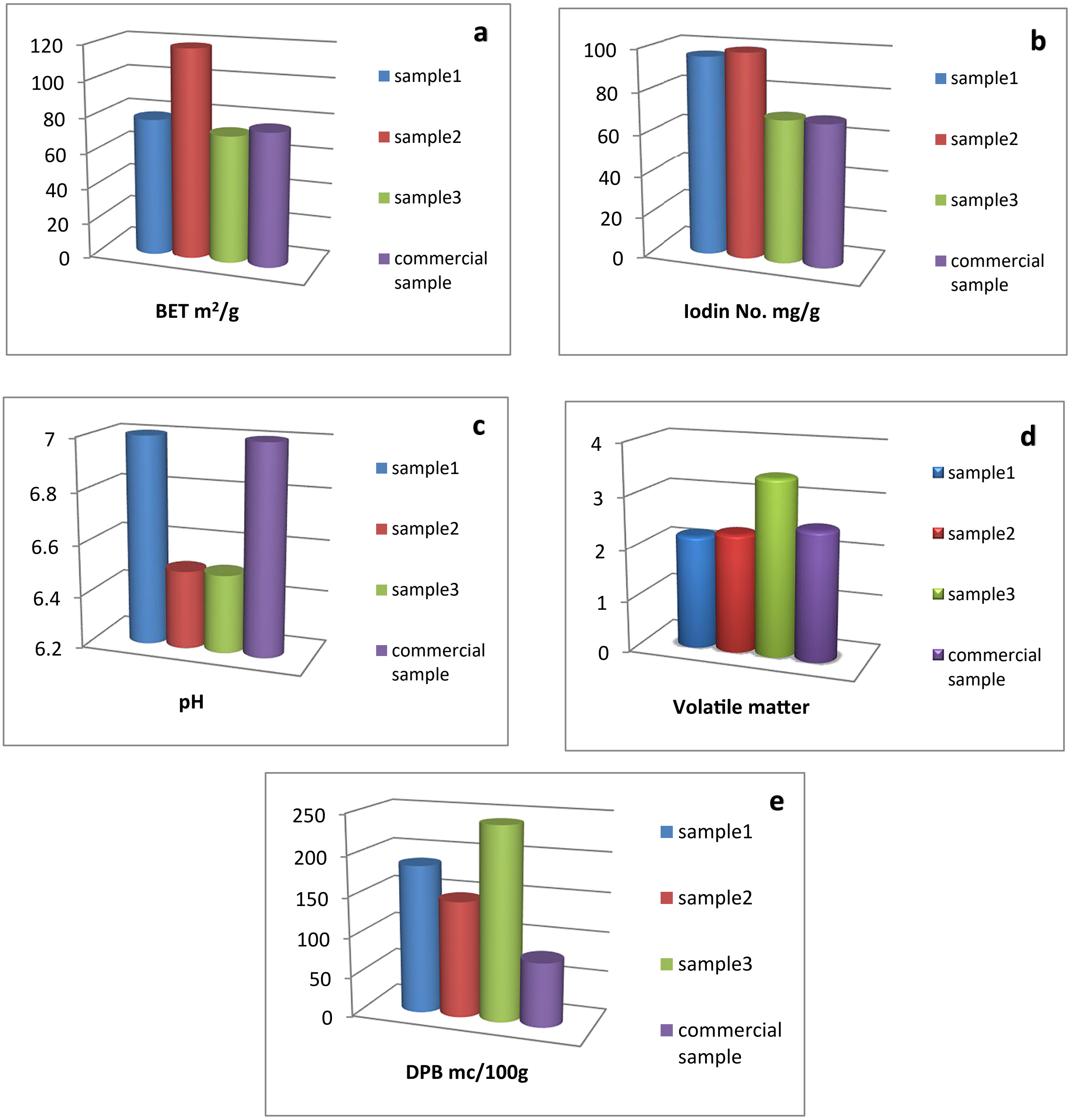

Fig. 4. Comparison of the characteristics between prepared samples and commercial carbon black: a) BET, b) Iodine No., c) pH, d) Volatile matter, e) DPB.

Table 7. Circumstances and properties of the prepared rubber mixture of the pilot plant.

Rubber mixture		Sample1	Sample2	Sample3	Commercial carbon	Rubber without carbon black
Circumstances for preparation of mixture	Type of mixture	SMR62	SMR62	SMR62	SMR62	SMR62
	Time of mixture	5R*	5R	4R	5R	10
	Temperature of press ° C	160	160	160	160	160
Mixture properties	Hardness Shore A	62	65	62	58	45
	Elongation %	560	525	555	600	664
	Tensile strength (D/cm²)	238	213	195	225	165

* R means the best time to press the rubber mixture. It is determined by using a rheometer device which gives the best time to complete vulcanization.

Table 8. Operation condition of prepared samples in the pilot plant.

Samples	Raw material	Temperature °C	Average of fuel flow L/H	Average of airflow L/H	Air/Fuel by weight
1	Gas oil	1200 >	9–7	28500	1/4.3
2	Gas oil	1200 >	9–8	28000	1/4.2
3	fuel oil	1180	15	17500	1/1.5

Table 9. Gas oil and fuel oil characteristics.

Characteristics	Gas oil	Fuel oil
Specific gravity in 15.6 °C	0.8398	0.9464
Viscosity in 37.8 °C (centistokes)	6	130
Viscosity in 50 °C (centistokes)	5	70
Pour point °C	9	10
Flashpoint °C	54	54
Sulfur content %weight	1.1	3.5
The heat of combustion (cal/g)	10800	10500
Carbon residue %weight	0.2	8

Kiln relationship with yield

The design of the kiln significantly impacts the yield of carbon black. Raw materials are converted into carbon black, coke, carbon oxides, and energy. The ratio of these materials varies depending on the kiln's design.[22,23] The kiln has been modified from a vertical to a horizontal design, and its diameter has been increased, as shown in Fig. 1. There is a good ability to improve these results if this pilot has a chance to continue the research and development. We must consider various aspects related to the factory that require additional effort to ensure an optimal industry from technical, economic, and environmental perspectives.

Conclusion

It was observed that the prepared carbon samples outperformed the commercial carbon samples due to their higher BET and iodine numbers. The second direction is to use prepared carbon samples and commercial carbon samples separately in SMR62 rubber mixtures. It was noted that the prepared samples gave acceptable results regarding the specifications of the resulting mixture. The hardness values are slightly higher than those of the commercial sample, whereas the elongation values are slightly lower but still fall within the acceptable limits for this type. Regarding tensile strength, the prepared samples provided values that are either close to or exceed those of the commercial sample.

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Authors' declaration

- Conflicts of Interest: None.
- We hereby confirm that all the figures and tables in the manuscript are ours. Furthermore, figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- No human studies are presented in manuscript.
- No animal studies are presented in manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at University of Duhok.

Authors' contribution statement

L. Y. Q. and W. K. E. developed the study design, conducted the experiment, and wrote the manuscript. N. Z. S. and H. M. A. analyzed the data and made revisions.

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تصميم وحدة ريادية مع ظروف تشغيل مناسبة لإنتاج أسود الكاربون من نوع SRF

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[4] *قسم تقنيات الصناعات الكيمياوية والنفطية، الجامعة التقنية الشمالية، نينوى، العراق.*

المستخلص

تم في هذا العمل تحقيق المعرفة التكنولوجية لإنتاج مادة اسود الكاربون من النوع (SRF) من خلال تصميم وبناء وحدة تجريبية تتكون من خمسة أجزاء رئيسية: فرن، برج تبريد، إعصار حلزوني، وحدة تصفية وفصل، وحدة تجفيف ومعالجة فيزيائية. تم استخدام زيت الغاز وزيت الوقود كمواد خام. تتكون المادة الخام الأولية للمنتج من الهيدروكربونات، والتي تنقسم إلى العناصر المكونة لها (الكربون والهيدروجين) إما عن طريق الاحتراق الجزئي أو الأكسدة الحرارية. من الناحية الاقتصادية، أصبح التحلل التأكسدي الحراري هو الطريقة السائدة، حيث تلعب الهيدروكربونات دورًا مزدوجًا لأنها تعمل كمصدر للحرارة وانتاج الكربون. يستخدم أسود الكربون في المقام الأول كحشوات فعالة او كعامل تقوية في خلطات المطاط المختلفة وخاصة الإطارات، وكصبغة سوداء في أحبار الطباعة والطلاء السطحي والورق والبلاستيك وغيرها من الاستخدامات. اعطت المواد الاولية المستخدمة محصولًا جيدًا وخصائص مشابهة للعينة التجارية عند تحديد واختيار ظروف تشغيل مناسبة. وقد تميز إنتاج اسود الكربون من زيت الغاز(في هذا المصنع التجريبي) حيث اعطى مواصفات أفضل واسلوب انتاج أسهل من زيت الوقود.

الكلمات المفتاحية: أسود الكربون نوع SRF، زيت الوقود، زيت الغاز، الاحتراق الجزئي، المصنع التجريبي.