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IDENTIFYING THE EFFECT OF ADDING CATALYTIC CONVERTER BRIQUETTE MIX VARIATIONS EMPLOYING THE MICROWAVE METHOD WITH SULFURIC ACID ACTIVATION TO REDUCE EMISSIONS IN MOTOR VEHICLES

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The use of fossil fuels in transportation equipment, especially motorized vehicles, will have an extraordinary effect on air pollution. The percentage of air pollution from transportation sources in Indonesia is 70.5 % CO, 18.34 % HC, 8.89 % NOx, 0.88 % SOx, and 1.33 % particulate matter. Given the danger of exhaust emissions, especially carbon monoxide, which can cause death for humans who inhale it, efforts are needed to control air pollution from motorized vehicles. There are several methods that can be applied, one of which is to use adsorbents. Activated carbon can be used as an adsorbent.

In this experimental research, briquettes with a diameter of 20 mm and a length of 30 mm were made. A mixture of coconut shell charcoal briquettes and wood charcoal briquettes 65–25 % (Model 1), 55–35 % (Model 2), and 45–45 % (Model 3) was used. The microwave method and sulfuric acid activation for 1 hour were applied. Testing with the object of the study was performed on a 4-stroke motor vehicle (Honda Supra 125) 2012 with an engine speed of 2,000 rpm. Emission tests were carried out using a gas analyzer. The performance test of a motorbike engine where adsorbents are installed in the exhaust gas was conducted using a dyno test. The results show that this briquette mixture can reduce carbon monoxide (CO) gas emissions by 71.6 % compared to without a catalytic converter. In addition, gas emissions of hydrocarbons (HC) were seen to be reduced by 88.8 % in comparison with an engine without a catalytic converter. Engine performance tests showed no significant impact on torque and power due to the use of this adsorbent.

In conclusion, a mixture of coconut shell charcoal briquettes and wood charcoal briquettes activated with sulfuric acid, which is used to reduce exhaust gas emissions in motor vehicles can be applied

Keywords: briquettes, wood charcoal, coconut shells, H_2SO_4 activation, CO, HC

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1. Introduction

Dependence on fossil fuels for transportation is still significant. However, another important factor that requires reducing the use of fossil fuels, especially petroleum in transportation, is the limited availability and relatively low cost of petroleum today. Research on current and future oil resources leads to the conclusion that these resources are quite limited. The maximum production level, which may have been reached or known as peak oil, is the result of research [1]. Current technological dependence on fossil fuels has increased [2]. Humanity faces significant challenges, including climate degradation and global warming. Approximately 25–30 % of a country's total CO_2 emissions come from the transportation sector [3]. Dependence on fossil fuels, especially for transportation, contributes to increased air pollution, worse traffic congestion on highways, and increased motor vehicle accidents [4, 5]. To address the problem of air pollution, one effective approach is to regulate exhaust emissions from vehicles [6–10].

On the other hand, air pollution is one of the common problems faced in urban areas, according to the United Nations Environment Program (UNEP) as many as 6.5 million people die each year due to exposure to poor air quality. In addition, 70 % of deaths due to air pollution occur in Asia including Indonesia. The transportation sector is the main source of pollution in urban areas [3]. Motor vehicle emissions contribute 70 % to Nitrogen Oxide (NOx), Carbon Monoxide (CO), Sulphur Dioxide (SO_2), and particulate (PM) pollution in urban areas. Emission testing is one of the testing efforts to determine engine performance and the level of combustion efficiency in motor vehicle engines. One effort to reduce air pollution is to design motor vehicles that produce exhaust gases with low pollutant concentrations.

Therefore, the use of microwave method and activation with sulfuric acid on briquettes not only increases the pore area of briquettes but also contributes to the reduction of impurities in briquettes. The adsorption capacity of briquettes becomes better. This is very relevant in the context of reducing exhaust emissions in the ambient air.

2. Literature review and problem statement

Several studies have reported on the adsorbent properties of activated carbon materials used to reduce exhaust emissions. However, there is limited information on the effects of adding rambutan wood charcoal and coconut shell briquettes, particularly when employing the microwave sulfuric acid activation method, to enhance emission adsorption in motor vehicles. Various techniques are available to minimize exhaust emissions from motor vehicles, especially those using gasoline. One approach is to manage exhaust gases such as carbon monoxide, carbon dioxide, nitrogen oxides, and ammonia through adsorption. Another method, incineration (or combustion), utilizes a hot oxide process to remove hydrocarbon gases found in pollutants. Combustion produces carbon dioxide (CO_2) and water (H_2O) condensation, hydrocarbon gas reverts to a liquid state. When exhaust gas comes into contact with this liquid, the hydrocarbons can dissolve through absorption. Additionally, chemical reactions are typically involved in the emission of nitrogen and sulfur compounds.

Research on advancements in CO_2 capture by absorption and adsorption: An extensive search has been made to accomplish this review by [11]. Effectively, for the emerging global climate change, carbon dioxide (CO_2) capture strategies have continued to stand as the only solution to controlling anthropogenic greenhouse gas emissions. This comprehensive review outlines the latest advancements in CO_2 capture, focusing on two primary methodologies: absorption and adsorption. The physical methods of solute transport across the cell membrane include thinking of the cell membrane as a barrier involved in processes such as absorption and adsorption.

In relation to these processes, the dynamics and the roles of new materials, this technology has only recently been introduced, especially in the last few years.

Whereas for absorption, the emphasis is on material design strategies and finding new materials from amines to IL and nanofluids classes with improved CO_2 capture capability and low energy requirements. In contrast, for adsorption, new adsorbents, including metal-organic frameworks (MOFs), organic polymers, inorganic adsorbents, Si-based adsorbents, biochar, and biomass by-products that potentially have higher selectivity and stability than the conventional adsorbents are synthesized. Also, the review includes the concerns of the scaling and applications of the techniques involved.

The study [12] considers carbon dioxide separation and capture by adsorption. The advancing unfavorable effects of climate change as a result of individuals' activities in the global environment necessitate refinement of technologies to decrease outputs of carbon dioxide. Bringing together the technology types for carbon dioxide capture, the present study briefly discusses materials, techniques, processes, manufacturing additives, direct air capture, machine learning, life cycle assessment, commercialization, and scaling up.

Furthermore, the research on analyzing the performance of cyclones and scrubbers as air pollution control methods for household solid waste incinerators

has been carried out by [13]. Treating household solid waste through incinerators can create environmental problems, as gas emissions from combustion are released. Air Pollution Control Devices (APCDs), such as cyclones and cyclone scrubbers, are often used to mitigate this issue. This study aims to evaluate the efficiency of cyclones and cyclone scrubbers as APCDs for incinerators. To conduct the study, SO_2, NOx, and CO gas emissions are measured from the combustion of mixed waste in an incinerator with a fixed waste composition. Data were collected every 5 minutes within 45 minutes of combustion at the inlet and outlet on each APCD. The results show that using cyclones can eliminate 37 % of NOx and 91 % of CO emissions. In contrast, cyclone scrubbers can eliminate 53 % of NOx and 96 % of CO emissions.

The paper [14] considers a novel cryogenic condensation system combined with gas turbines for low carbon emission volatile compound recovery. The problem of volatile organic compounds (VOC) has recently gained much attention globally given its effect on environment pollution, climate change, and human health among others. VOC recovery through condensation is thus a feasible method; however, there is a challenge concerning energy consumption, carbon emission, refrigerant use and the VOC emission concentration. This paper presents a new configuration of extraction and condensation of VOCs and integration with a gas turbine. The heat gained through partial combustion of the exhaust is used to operate an ammonia liquid absorber refrigerator and a helium Stirling refrigerator to regenerate VOCs in the residual exhaust gas. This system has the benefits of no extra power supply, no emission of any greenhouse gases, utilizing natural means of refrigeration and nearly no emission of volatile organic compounds. Thus, for the highest effective recovery, a thermodynamic calculation model was created and tested in related experiments. It was also seen that 93.3 % of VOCs were potentially recoverable if 6.7 % of VOCs were burnt whereby, the absorber refrigerator of 213 K was recuperating the waste heat from the gas turbine, which was utilized to run the Stirling refrigerator of 110 K. Twenty eight percent reduction efficiency in the use of fossil fuel with a reduction of 16707 tons of carbon per year was achieved with a reduction efficiency of 92.9 %.

Furthermore, the study about numerical simulation of ammonia/methane/air combustion using a reduced chemical kinetic model was conducted by [15]. Ammonia is one of the promising options for its application as a hydrogen carrier and as a fuel in gas turbines and internal combustion engines. It is critically important to understand the chemical process that ammonia burns through if combustion systems for ammonia are to be designed and if the injurious NOx emissions are hence to be contained. However, in light of many experimental and modeling studies on ammonia combustion, it is still necessary to focus more on the kinetics of combustion processes. The purpose of this research was to perform modeling of the ammonia combustion chemistry and identify the reaction conditions similar to the industrial ones. Based on a literature survey, three ammonia combustion mechanisms involving carbon chemistry were employed to model an experimental premixed swirl burner to assess its prospect. While the San Diego mechanism is the most comprehensive, it was identified to provide the best emissions predictions and, unfortunately, none of the models captured CO emissions beyond the equivalence ratio of 0.81.

Compared to other methods mentioned above, the following are some of the benefits of adsorption methods, namely: adsorption methods are simple in design and hence cost-effective, and it is an excellent way of removing organic pollutants and the process itself is quite straightforward [16]. Thus, the only adsorption method was employed in this investigation.

Numerous investigations on the physical, technical, and chemical treatment have been made to minimize exhaust emissions pollutants [17]. Among the measures that can be implemented to minimize pollution, installation of a catalytic converter [18] especially with activated carbon briquettes is the most efficient.

According to the researcher [19], activated carbon is a carbon compound, which has been through a process of carbonization and activation in order to boost its adsorption ability. Activated carbon is an amorphous carbon and it can be made from carbonaceous material or charcoal to which a larger pore surface area has been subjected to. This property allows activated carbon to absorb gases, liquids or dissolved substances in it. Coconut shell-based activated carbon can be used as an adsorbent due to several advantages, as stated by [20], including:

– selective adsorption capacity;

– open structure that means it has a large external surface area for a unit of mass;

– high sorption capacity for the purpose of physically or chemically separating one substance from the other.

Previous research relevant to this topic has examined the use of fly ash as a catalytic converter to reduce CO and HC emissions, as noted by researchers [21]. At an engine speed of 2,000 rpm and a catalyst length of 9 cm, the minimum recorded CO and HC emission levels are 1,260 ppm and 8,510 ppm, respectively.

Other research done on peat soil adsorbents and filter variations in the exhaust pipes for the reduction of motorcycle emissions includes [22]. The method used was activated carbon, which was prepared in the form of briquettes. Model 1 had a cross section of 20 mm while Model 2 had an outer cross section of 20 mm and an inner cross sectional diameter of 10 mm and Model 3 contained no adsorbent. The comparison was done on Model 1, Model 2, and Model 3, and according to the results, it was found that Model 2 performed the best in terms of minimizing emission levels.

Available research about the impact of incorporating a catalytic converter together with different wood charcoal briquettes on performance and emission was carried out by [23, 24]. In the study, catalytic converters with solid cylindrical briquettes, perforated cylinders exhausts and standard exhausts were employed. The measurements were conducted on idle engine speed, the engine speed being set at 2,000 rpm above the idle limit. The results obtained were as follows: HC exhaust emissions, perforated cylinder=341 ppm, while for solid cylinder=601 ppm, and standard exhaust=1,894 ppm.

However, there were unresolved issues related to the quality of the briquettes produced, which was still lower than optimal, the reason being that the pores of the briquettes formed still contained impurities and the pore surface area of the charcoal briquettes was not too large. The problem analysis from previous research on this matter is still unresolved and there is no conclusion at all. A way to overcome these difficulties is to carry out the carbonization process using the microwave method, which was previously activated with sulfuric acid/H_2SO_4 when made into activated charcoal. This approach was used in [19].

In general, the above research is a study on catalytic converters containing briquettes/activated carbon to reduce exhaust emissions, but there are still unresolved problems, namely the presence of impurities and very small pores in the briquettes. A way to overcome these difficulties is to carry out the carbonization process using the microwave method, which was previously activated with sulfuric acid/H_2SO_4 when made into activated charcoal. This approach was used in [19]. Therefore, in this work all suggestions were followed to conduct a study.

3. The aim and objectives of the study

The aim of this study is to identify the effect of adding rambutan wood charcoal briquettes and coconut shell briquettes, particularly when employing the microwave sulfuric acid activation method, to enhance emission adsorption in motor vehicles.

To achieve this aim, the following objectives are accomplished:

– to investigate the effect of adding rambutan wood charcoal and coconut shell briquette catalytic converters, activated using the microwave method and sulfuric acid, on carbon monoxide (CO) exhaust emissions;

– to examine the effect of these additives on hydrocarbon (HC) exhaust emissions;

– to analyze how the addition of rambutan wood charcoal and coconut shell briquette catalytic converters influences engine performance, including torque and power;

– to find out the effect of rambutan wood charcoal and coconut shell briquettes using the microwave method and sulfuric acid activation from the testing side.

4. Materials and methods

4. 1. Object and hypothesis of the study

The object of the study is the emissions in motor vehicles when using fossil fuels. The following is a list of data that will be used in this research, including:

1. Validation of data combined with previous research.

2. CO and HC emission data from motor vehicles that use a mixture of coconut shell charcoal briquettes and wood charcoal briquettes with a proportion of 65–25 % (Model 1), 55–35 % (Model 2), and 45–45 % (Model 3), which are installed on the catalytic converter in the exhaust system.

The variation of rpm data in this study is 1,000 rpm, 2,000 rpm (idle condition), and 3,000 rpm. A gas analyzer is used to measure CO emissions in percentage and HC emissions in ppm. The data taken are emissions with standard exhaust/without catalytic converter and exhaust emissions using a catalytic converter.

3. The object of the study is a 4-stroke motorcycle with several assumptions: the motorcycle is well maintained, has premium fuel, and the year of use is 2012. Motorcycle performance data was collected through the use of a combination/mixture of adsorbers mounted on the exhaust, using Dyno Test VR-Tech V1.5. This data includes power and torque measurements, with power recorded in Nm and

torque in hp for each rpm change. The rpm variations examined in this study included 1,000 rpm, 2,000 rpm, 3,000 rpm, 4,000 rpm, 5,000 rpm, 6,000 rpm, and 7,000 rpm. In addition, the relationship between torque and rpm, as well as power and rpm, was plotted using Tecplot-360.

The main hypothesis of this study is that the microwave method/physical activation method and chemical activation of sulfuric acid can affect the quality of activated carbon briquettes produced. The assumption made in this study is that with the microwave method and sulfuric acid activation, it is expected that the briquettes will experience an increase in the pore size and a reduction in impurities in the briquettes. The simplification adopted in the work is to soak the briquettes in sulfuric acid for 1 hour.

4. 2. Research methodology for exhaust emissions

4. 2. 1. Preparation stage

Preparation includes conducting field surveys, installing equipment, taking samples, making activated carbon specimens, and designing adsorbent materials. In addition, preparation includes installing test machines and verifying their operational conditions:

1. Carbonization method for briquette materials. The microwave carbonization method consists in heating prepared briquettes at a temperature of 200–350 °C, which were previously activated with sulfuric acid (H_2SO_4).

2. Sulfuric acid activation (H_2SO_4). The purpose of this work is to compare the effects of employing microwave-carbonized and sulfuric acid-activated wood charcoal and coconut shell charcoal briquettes as a fuel on the emissions and efficiency of the engine. The briquettes were treated with the H_2SO_4 activator and immersed in it for 90 minutes. Subsequently, the microwave carbonization and sulfuric acid-activated briquettes were tested on the catalytic converter. In this work, the experimental data collected was analyzed and processed using Tecplot software.

3. Briquette model variations. Table 1 below shows the composition of briquette materials used for testing in this study.

Table 1

Composition of briquette materials

No.	Percentage of briquette material		
	Coconut shell charcoal, %	Wood powder, %	Rambutan wood charcoal, %
Model 1	65	10	25
Model 2	55	10	35
Model 3	45	10	45

4. Briquette design. For more details, the briquette design can be seen in Fig. 1 below.

a *b* *c*

Fig. 1. Image of briquettes and briquette arrangement in the catalytic converter: *a* – briquettes; *b* – inside of the catalytic converter; *c* – arrangement

The details of the catalytic converter installation can be seen in the following Fig. 2.

Information about the detailed dimensions of the catalytic converter can be found in the following Fig. 3.

Fig. 3 above is a detailed image of the dimensions of the catalytic converter, where the adsorbent is installed. The total length of the converter is 150 mm, and the center is 80 mm long.

Fig. 2. Placement of the catalytic converter

Source: [4]

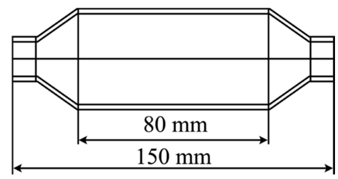


Fig. 3. Catalytic converter dimensions

4. 2. 2. Main phase

In this main phase, what is done is conducting tests. Two tests are carried out:

a) activated carbon testing. This test is intended to identify the characteristics of activated carbon. It is important to determine the surface topographies of materials and the pore diameter of the briquette surface using Scanning Electron Microscopy (SEM). Energy Dispersive X-Ray Spectroscopy or often abbreviated as EDX is one of the most useful tools to determine the elemental composition of the analyzed sample. FTIR or Fourier Transform Infrared Spectroscopy is used to find out the bonds between molecules through infrared energy. Iodine is a test to assess the adsorption capacity of activated charcoal briquettes;

b) testing of emissions and performance:

1) in this case, measurements of CO and HC emissions, along with motorcycle performance, are carried out without including activated carbon. These findings serve as necessary controls for future experiments;

2) the activated carbon sample, which is circular with a diameter of 20 mm and a length of 30 mm, is placed in the exhaust pipe, where CO and HC emissions are assessed at the same time as the motorcycle's performance is recorded. Analysis of the results will be carried out to ensure the reduction of CO and HC emissions. To calculate the percentage reduction, the average measurements before and after the installation of the absorbent sample will be compared.

5. Research results on the influence of wood charcoal and coconut shell charcoal briquettes mixture with sulfuric acid activation

5. 1. The influence of wood charcoal and coconut shell charcoal briquettes mixture with sulfuric acid activation on CO emissions

The effectiveness of the briquette mixture as an adsorbent of emissions from motorcycles has been studied based on tests on a 2012 Honda Supra 125 cc 4 stroke motorcycle. Fig. 4 details CO results.

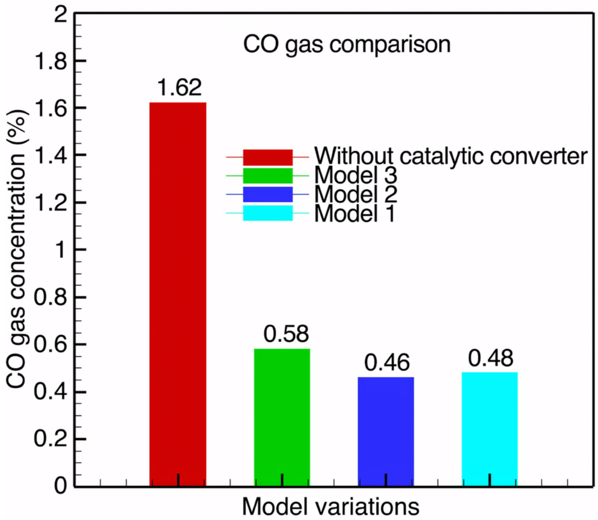


Fig. 4. Comparison of the CO emission between briquette catalytic converters variations and without catalytic converter

Fig. 4 reveals a comparative analysis of CO emissions with a standard exhaust system and a catalytic converter and the effect of the briquette mixture of wood and coconut shell charcoal in the ratios of 65–25 % (Model 1), 55–35 % (Model 2), and 45–45 % (Model 3). The figure shows that exhaust without the catalytic converter emits higher CO emissions than emissions of vehicles fitted with the catalytic converter. Of the called variations, the lowest CO emissions are produced by the 55–35 % (Model 2) mix of coconut shell charcoal to wood charcoal. This is in agreement with [15] who compared the catalytic converters made from the coconut shell with those made from wood charcoal where he noted that the former has a higher ability of absorbing the exhaust gases. Further, the iodine absorption studies reveal that the Model 2 or 55–35 % mixture has the highest iodine adsorption.

5. 2. Comparison of HC emission reduction between wood charcoal and coconut shell charcoal briquettes with sulfuric acid activation

The following section discusses the results of the research on HC emissions. Fig. 5 presents the findings related to HC emissions.

Fig. 5 shows the HC emission in the standard exhaust and with the use of catalytic converters while using different mixtures of wood and coconut shell charcoal (65–25 %, 55–35 %, and 45–45 %). Comparing the exhaust system without the converter and that with the catalytic converter, the former is seen to release much higher levels of HC than the latter. However, of all these mixtures the one with the least percentage of HC emissions is the one made out of 55 % coconut shell charcoal and 35 % wood charcoal. As with the results of the CO test, the study of [15] revealed that the catalytic converter made from coconut shells has higher efficiency in the absorption of exhaust gases than wood charcoal. In the iodine absorption tests, the highest percentage absorptivity was recorded for the 55–35 mixture or Model 2.

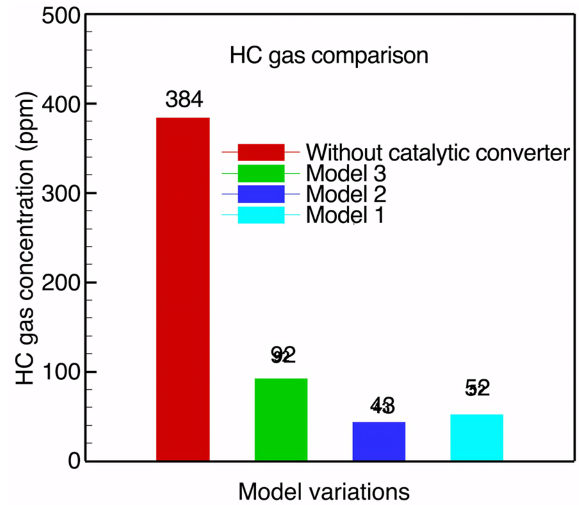


Fig. 5. Comparison of the hydrocarbon emission between briquette catalytic converters variations and no catalytic converter

5. 3. Identifying the influence of microwave method and sulfuric acid activation briquettes on power and torque

5. 3. 1. Results of power output

Data collection for engine performance was also carried out. The power output for various models is shown in Fig. 6.

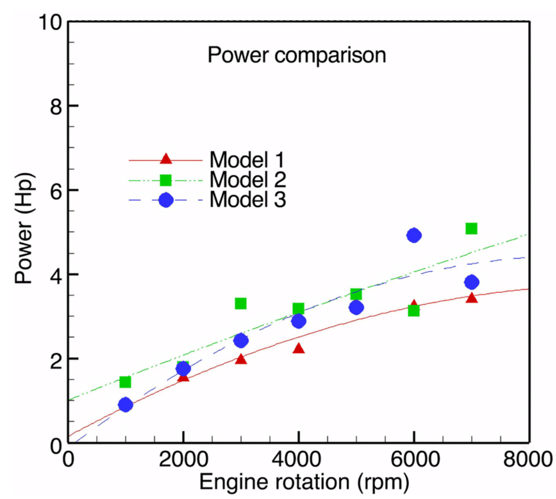


Fig. 6. Power output from dyno test

As illustrated in Fig. 6, the power output for all the briquette mixtures was determined and recorded after installation in the catalytic converter. It is found that the power output of an engine increases with an increase in the engine speed. However, a comparison of the various mixtures shows that the power output is similar for the different briquette compositions indicating that the motorbike performance is not compromised. The difference in power output between the two compositions is calculated as $(0.89-0.87)/0.89\times100\ \%=2.2\ \%$. It means that there is no significant difference between the two mixtures and no added power boost observed.

5. 3. 2. Results of torque output

The results of the torque tests for various models are shown in Fig. 7 below.

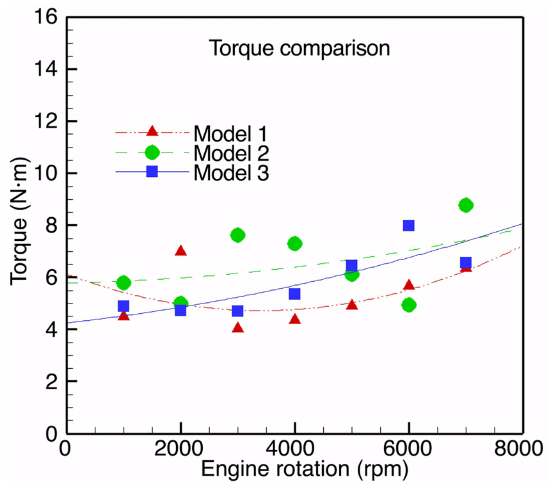


Fig. 7. Torque curve from dyno test

Fig. 7 above shows the torque differences of all the briquette mixtures used within the catalytic converter. Usually, there is a directly proportional relationship between torque and RPM such that with a higher RPM there is also a higher torque. Nevertheless, it is noteworthy to understand that the quantity of torque developed by various briquette mixtures is not far from each other, meaning there is no drastic difference in engine power. The difference between the highest and lowest torque values is calculated as (4.69–4.01)/4.69×100 %=14.4 %. This implies that the differences in torque between the mixtures are not significant.

5. 4. Identifying the influence of microwave method and sulfuric acid activation briquettes from the testing side

5. 4. 1. Validation

Table 2 below presents the results of the study when compared to the previous study conducted by the researcher [17] at the same rpm of 2,000, specifically examining CO and HC emissions from standard motorcycle exhaust or without a catalytic converter.

Table 2

The validity of compliance of standard motorcycle emissions without utilizing a catalytic converter

No.	Vehicle type	CO
1	Research by [17] (Kharisma)	1.57 %
2	Present study (Supra X)	1.62 %

Table 2 above highlights CO emissions from the previous study done by [17] and the present study. The overall difference in CO emissions is (1.57–1.62)/1.57×100 %=3.18 %.

5. 4. 2. Scanning electron microscopy (SEM) analysis

Scanning Electron Microscopy (SEM) is used in surface topographies of materials and can give data as to the chemical makeup of both metallic and non-metallic materials. It has a large FOV and is able to magnify objects up to one to two million times and hence produces images that are more detailed than those of light microscopes. For instance, Fig. 8 represents SEM images of samples at a magnification rate of 512x.

The SEM image of the activated carbon surface given in Fig. 8 reveals the differences between non-activated carbon and activated carbon. From the above pictures, it can be observed that the surface of the activated adsorbents appears to be cleaner than that of the non-activated adsorbents. The non-activated carbon pores are between 8.994–13.6 μm in diameter, however, the micropores are not discernible because impurities fully obscure the pores' surface. For activated carbon treated with H_2SO_4, macropores are between 12.22–14.34 μm, while micropores are between 13 and 2.417–4.294 μm with the sample being cleaner than the earlier ones in terms of adsorbent surface. Activation leads to the formation of a larger surface area of adsorbent as well as a larger pore volume. By activation of H_2SO_4, certain inorganic compounds coating the pores are dissolved, which results in more open pores and more pore formation. The study conducted by [25] shows that with a large surface area, it has better adsorption properties. The pore surface area of model 2 is large and free of contaminants and impurities, therefore, capable of trapping the maximum levels of CO and HC emissions as compared to the other models.

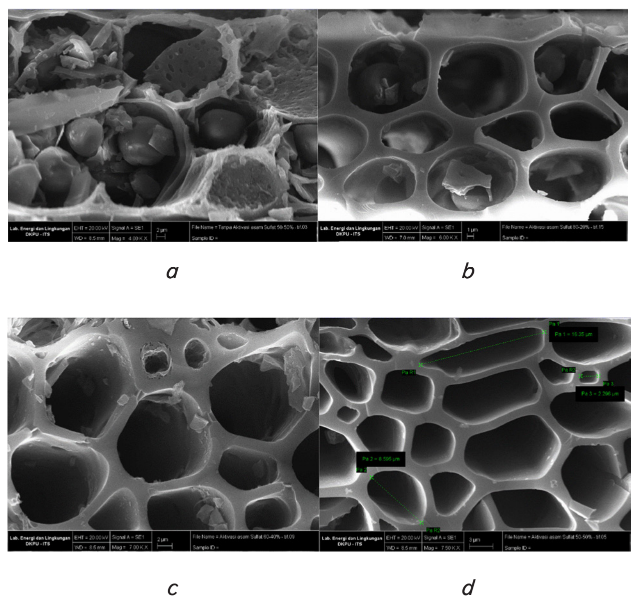
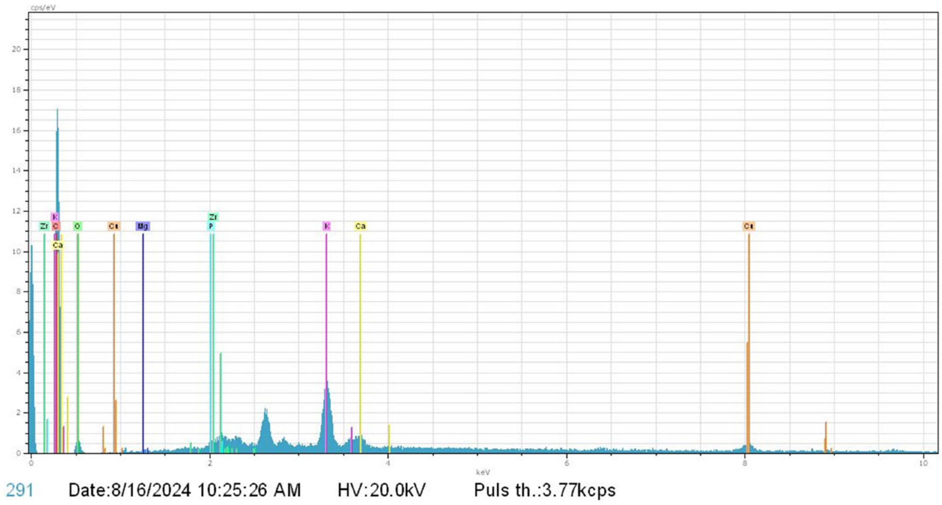


Fig. 8. Scanning electron microscopy test results: *a* – without activation; *b* – model 1 activation; *c* – model 2 activation; *d* – model 3 activation

5. 4. 3. Energy dispersive X-ray spectroscopy (EDX) analysis

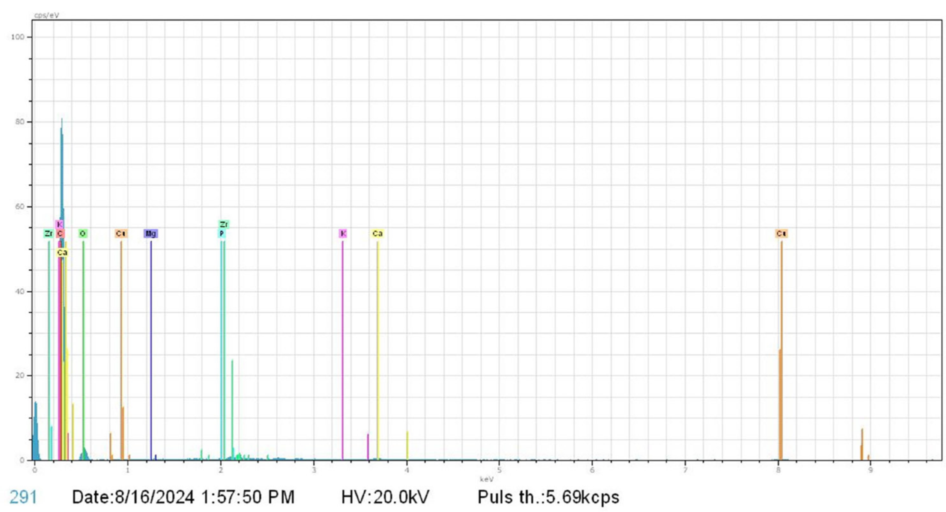
Energy dispersive X-ray spectroscopy or often abbreviated as EDX is one of the most useful tools to determine the elemental composition of the analyzed sample. The EDX proves useful to investigators since it enables them to determine detailed chemical information on the macroscales, microscales, and nanoscales of the specimens. The results of the EDX test can be seen in Fig. 9, 10 below.

Fig. 9, 10 show the analysis of the acquired results for the elemental composition of the wood charcoal as well as the coconut shell charcoal briquettes obtained by soaking in H_2SO_4 activation for one hour alongside Models 1, 2, and 3. The EDX results for Model 1: the carbon percentages present are C 69.39 %, O 26.13 %, Cu 1.97 %, Zr 1.85 %, Ca 0.51 %, K 0.14 %, Mg 0.02 %, F 0 %. For Model 2: C 79.39 **%**, O 17.79 %, Cu 1.69 %, Zr 0.9 %, Ca 0.04 %, K 0.03 %, Mg 0 %, F 0 %. Then, for Model 3: C 72.18 **%**, O 21.82 %, K 2.15 %, Cu 1.74 %, Zr 1.71 %, Ca 0.36 %, K 0.03 %, Mg 0.03 %, F 0 %. We can therefore conclude that the C percentage is high in all the models with Model 2 having the highest value at 79.39 % C. As for the emission tests, Model 2 also has the least CO emissions, in a way that imposes greater reactivity as well as ability to absorb CO from exhaust gases. This trend also applies to HC emissions.



El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
C	6	K-series	70.73	70.73	80.26	24.6
O	8	K-series	20.63	20.64	17.58	8.5
Cu	29	K-series	3.16	3.16	0.68	0.1
K	19	K-series	2.76	2.76	0.96	0.1
Zr	40	L-series	2.07	2.07	0.31	0.2
Ca	20	K-series	0.64	0.64	0.22	0.1
Mg	12	K-series	0.00	0.00	0.00	0.0
P	15	K-series	0.00	0.00	0.00	0.0
		Total:	100.00	100.00	100.00	

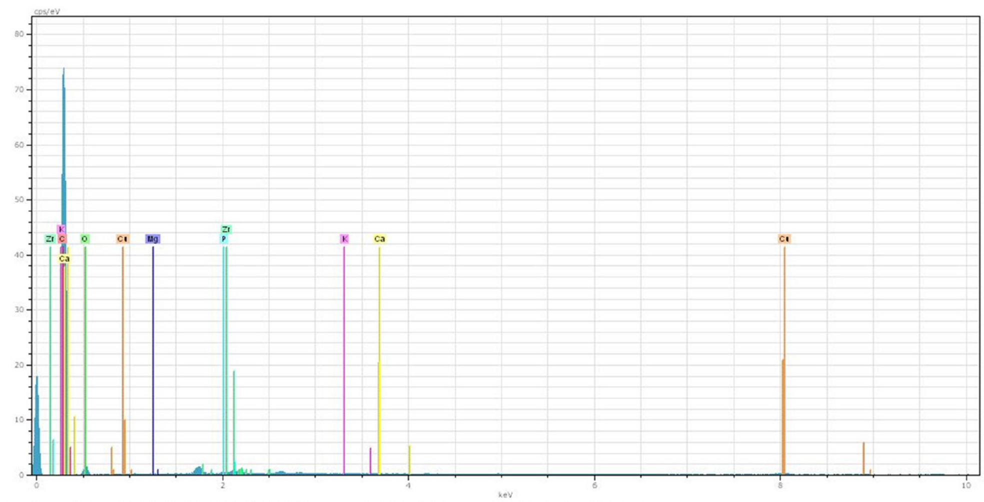
a



El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
C	6	K-series	69.39	69.39	77.25	22.3
O	8	K-series	26.13	26.13	21.84	9.0
Cu	29	K-series	1.97	1.97	0.41	0.1
Zr	40	L-series	1.85	1.85	0.27	0.2
Ca	20	K-series	0.51	0.51	0.17	0.1
K	19	K-series	0.14	0.14	0.05	0.0
Mg	12	K-series	0.02	0.02	0.01	0.0
P	15	K-series	0.00	0.00	0.00	0.0
		Total:	100.00	100.00	100.00	

b

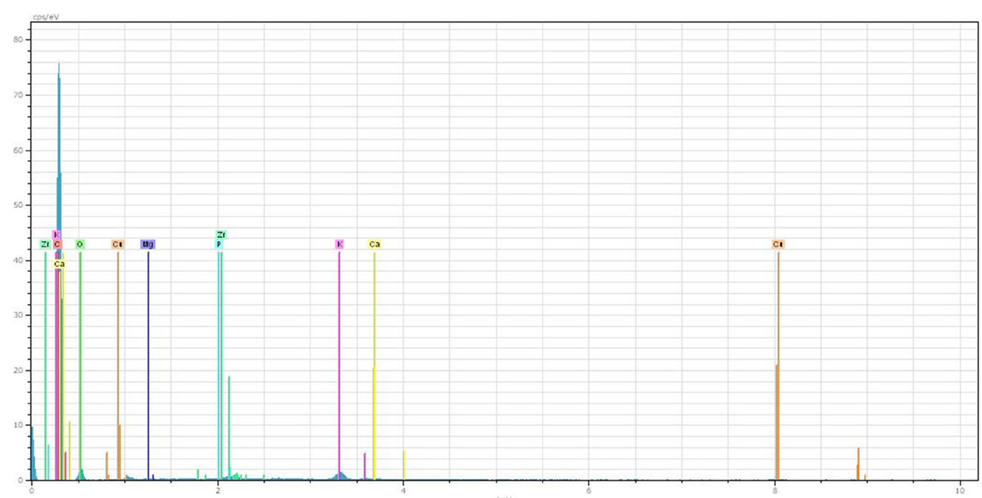
Fig. 9. Energy dispersive X-Ray spectroscopy results. Part 1: *a* – non-activation; *b* – model 1 activation



291 Date:8/16/2024 10:57:28 AM HV:20.0kV Puls th.:5.98kcps

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
C	6	K-series	79.57	79.57	85.21	25.6
O	8	K-series	17.79	17.79	14.30	6.5
Cu	29	K-series	1.68	1.68	0.34	0.1
Zr	40	L-series	0.90	0.90	0.13	0.1
Ca	20	K-series	0.04	0.04	0.01	0.0
K	19	K-series	0.03	0.03	0.01	0.0
Mg	12	K-series	0.00	0.00	0.00	0.0
P	15	K-series	0.00	0.00	0.00	0.0
		Total:	100.00	100.00	100.00	

a



291 Date:8/16/2024 10:34:07 AM HV:20.0kV Puls th.:5.33kcps

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
C	6	K-series	72.18	72.18	80.29	23.3
O	8	K-series	21.82	21.82	18.22	7.8
K	19	K-series	2.15	2.15	0.74	0.1
Cu	29	K-series	1.74	1.74	0.37	0.1
Zr	40	L-series	1.71	1.71	0.25	0.2
Ca	20	K-series	0.36	0.36	0.12	0.0
Mg	12	K-series	0.03	0.03	0.02	0.0
P	15	K-series	0.00	0.00	0.00	0.0
		Total:	100.00	100.00	100.00	

b

Fig. 10. Energy dispersive X-Ray spectroscopy results. Part 2: *a* – model 2 activation; *b* – model 3 activation

5. 4. 4. Iodine test

To assess the adsorption capacity of activated charcoal briquettes, the following table presents the iodine test results. The results of the iodine test are shown in Table 3.

Table 3

Iodine test results for briquettes with and without activation

No.	Testing variations	Iodine number
1	Without the activation process	1192.86 mg/g
2	With the activation process	1243.62 mg/g

Table 3 shows the comparison of the iodine test done on samples of briquettes with and without the activation process. Overall, it can be observed that the iodine number of the activated briquettes has been higher with a value of 1,243.62 mg/g. This suggests that the activated briquettes have been having a progressively higher adsorption capacity.

5. 4. 5. Fourier transform infrared spectroscopy (FTIR) analysis

FTIR is more focused on studying the behaviors of the material in relation to infrared radiation. The different types of molecules within the sample take up specific regions of the infrared energy causing variation in vibrational and rotational molecular. The results of the FTIR test for non-activation and activation can be seen in Fig. 11 below.

As we can see from Fig. 11, the FTIR spectrum of the non-activated model (*a*) exhibits absorption bands at 3380.76 cm^{-1} with OH functional group, total 2112.85 cm^{-1} (alkyne C≡C) and 1574 cm^{-1} shows C-C alkene vibration and the last is the wave number 873.62 cm^{-1}, which represents the C-O inorganic carbonate functional group. For Model 2 (*b*), it has an absorption band at a wavelength of 3599.64 cm^{-1}, which corresponds to the OH phenol functional group, reinforced by an absorption band at 2114.01 cm^{-1} representing C-C alkyne, and 1697.13 cm^{-1} showing C-O aldehyde vibration. Lastly, the wave number 1576.31 cm^{-1} indicates the C-C aromatic functional group. In general, from the activated charcoal absorption the above functional groups include OH, C-H, C-O and C=C. OH and C-O bonds depict that the activated charcoal is polar in nature and capable of adsorbing polar materials, which is widely used in water purification of sugar, alcohol, a killer of formaldehyde and exhaust gases.

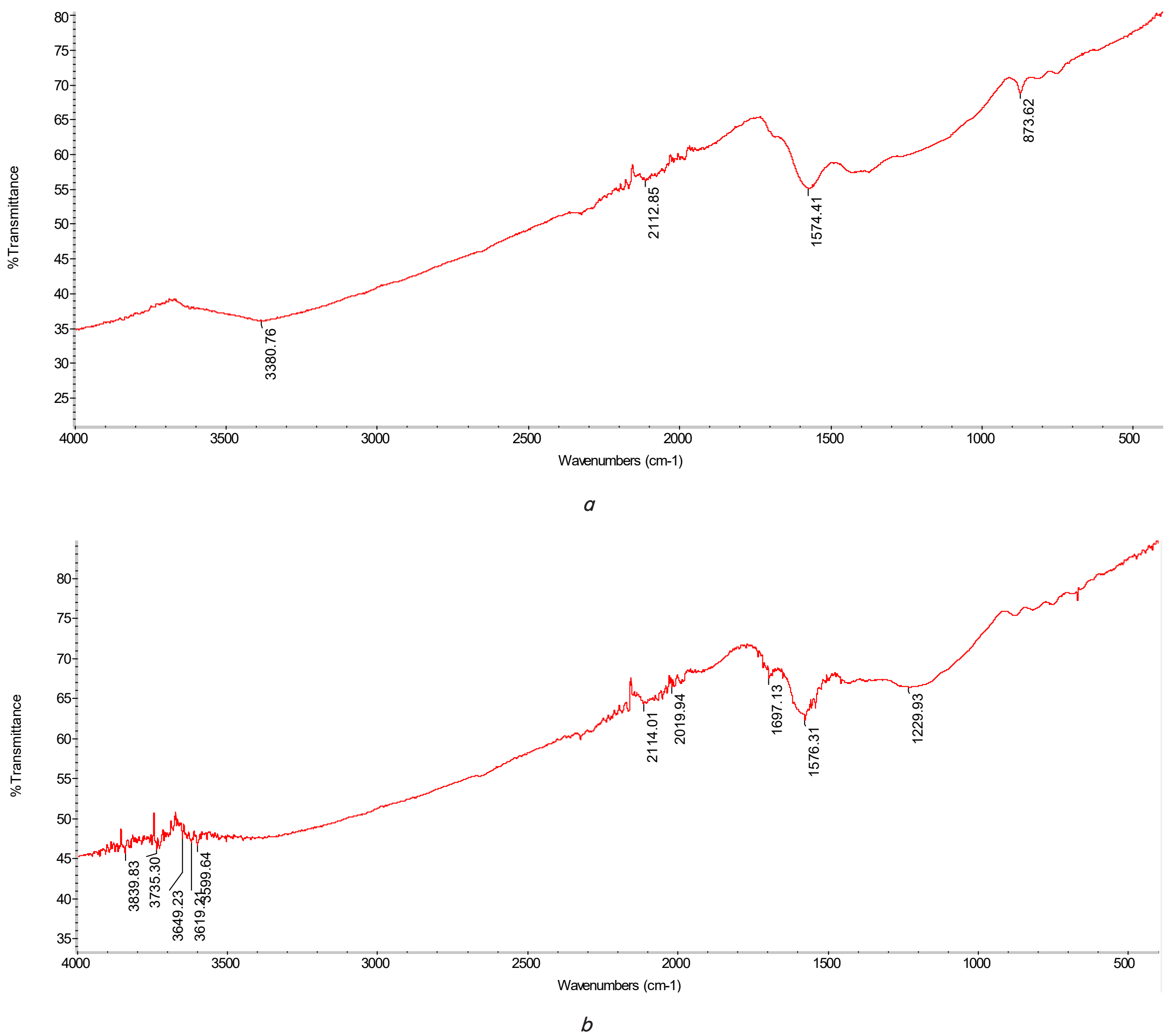


Fig. 11. Fourier transform infrared spectroscopy results: *a* — with activation; *b* — without activation

6. Discussion of the experiment results on the effect of mixed briquettes using the microwave method and sulfuric acid activation on exhaust gases

Based on the research data presented in Fig. 4, the minimum recorded CO emission is 0.48 % (Model 2), which occurs at 2,000 rpm engine rotation using a catalytic converter made of rambutan wood charcoal briquettes and coconut shell briquettes activated with sulfuric acid and using the microwave method. In contrast, the carbon monoxide (CO) emission value for a test machine without a catalytic converter is 1.62 %. This test showed a decrease of 71.6 %. Research [12] showed that the activation process produces more pores and pore cavities with greater depth. The activation process causes many volatile compounds to be released, thus opening the carbon pores and increasing the adsorption capacity. Coconut shell-based activated carbon has several advantages, as stated by [15], including selective adsorption capacity, open structure, and high sorption capacity.

On the other hand, from the research data in Fig. 5 the lowest HC emission is 43 ppm (model 2) using rambutan wood charcoal and coconut shell briquette catalytic converter activation using microwave and sulfuric acid methods. When compared with the hydrocarbon (HC) emission value of the test machine without using a catalytic converter, it is 384 ppm. The results of this test show a decrease of 88.8 %. This is supported by SEM test data, EDX test, iodine test, and FTIR test.

Based on the results presented in Fig. 6, 7 regarding the performance testing of motorcycles with mixed adsorbents, it can be ascertained that the addition of adsorbents does not have a negative impact on motorcycle performance. The performance results of the motorcycle with the object under test were almost identical, which indicates that the engine is operating without making abnormal sounds, or in other words, the engine is not damaged/the engine shuts down. The conclusion is that the performance of the motorcycle is not affected by the use of mixed adsorbents. Researchers [20] achieved similar findings, which showed that motorcycles using peat soil adsorbents with exhaust gas filters did not show significant performance improvements.

The SEM test shown in Fig. 8 demonstrated that the pore area looks larger and there is no dirt on the pore surface of the briquettes. In general, the largest pore area is model 2. The study by [21] shows that with a large surface area of the pore, it has better adsorption properties. On the other hand, based on the EDX test in Fig. 9, 10, it can be concluded that the C percentage is high in all models but Model 2 has the highest value at 79.39 % C so that it can absorb more CO emissions.

The validation of research results is given in Table 2. Validation was carried out with previous researchers, namely [17]. The conditions are designed according to the experimental conditions of the earlier researchers. The results are presumably in good agreement with previous studies due to the overall difference in CO emissions of 3.18 %.

From Table 3, the iodine number of the activated briquettes has been higher with a value of 1243.62 mg/g. This suggests that the activated briquettes have been having a progressively higher adsorption capacity. Finally, from the FTIR side shown in Fig. 11, in general, from the absorption of activated carbon there are functional groups OH, C-H, C-O, and C=C. The OH and C-O bonds illustrate that activated carbon is polar and can absorb polar materials that are widely used in the purification of sugar water, alcohol, formaldehyde, and exhaust gas.

The advantages of this research on rambutan wood charcoal adsorbent and coconut shell briquette catalytic converter activation using microwave and sulfuric acid methods installed on the exhaust of a Supra X 125 cc 4 stroke 2012 motor vehicle are as follows: in general, it can reduce CO exhaust emissions by 71.6 % when compared to motorcycle emissions without using a catalytic converter or in other words a standard motorcycle. On the other hand, it can reduce HC exhaust emissions by 88.8 % when compared to motorcycle emissions without a catalytic converter or a standard motorcycle. Another advantage is that according to the SEM test results, it can be seen that there is no visible dirt on the surface of the briquette and the briquette pore holes tend to be larger.

The limitation of this study is that the adsorbent of rambutan wood charcoal and coconut shell briquette catalytic converter activated using the microwave method and sulfuric acid installed on the exhaust of a Supra X 125 cc 4 stroke, 2012 motor vehicle, will be exhausted, through a continuous adsorption process. Peak CO emissions from gasoline engines are generated when the engine is at rest when the engine is slowing down and at low speeds. As a result, the speeds for emissions testing are in the range of 1,000 rpm, 2,000 rpm, and 3,000 rpm. Due to its limited horsepower (hp), it is not suitable for testing in open areas. To improve the quality of these testing tools, it is necessary to develop them by adding additional materials to the adsorbent. Adjustment on the carburetor needs to be completed first. This examination is only suitable for evaluation using gas analysis tools. Testing with activated carbon is essential for assessing moisture content, ash content, and morphology.

Further research can be done by recycling this briquette mixture by adding binding material elements to its composition, such as TiO_2 to increase the binding power so that the briquettes can last longer run out and the briquette mixture does not break easily.

7. Conclusions

1. Without a catalytic converter, CO gas emissions are 1.62 %, while using mixed briquettes (Model 2) – 0.46 %, thus the difference between without and with a catalytic converter is 71.6 %. That is this setup reduced carbon monoxide (CO) gas emissions by 71.6 %. The CO and HC exhaust gas emission output from this study is still below the threshold.

2. Hydrocarbon (HC) gas emissions saw an impressive reduction of 88.8 % when compared to engines without catalytic converters.

3. The engine performance tests showed no significant impact on torque or power due to the use of this adsorbent. In conclusion, the mixture of coconut shell and rambutan wood charcoal briquettes, activated through microwave and H_2SO_4 methods, effectively reduces exhaust emissions in motor vehicles and is suitable for practical application. The difference between the highest and lowest power values is 2.2 %. While the variation between the maximum and minimum torque values is 14.4 %.

4. SEM test showed the same results, namely that the pore area looks larger and there is no dirt on the pore surface of the briquettes. In general, the largest pore area is model 2. From the EDX test it can be concluded that the C percentage is high in all models but Model 2 has the highest value

at 79.39 % C so that it can absorb more CO emissions. The iodine number of the activated briquettes has been higher with a value of 1,243. 62 mg/g. The activated briquettes have been having a progressively higher adsorption capacity. Finally, from the FTIR side, in general, from the absorption of activated carbon, there are OH, C-H, C-O, and C=C functional groups. This activated carbon is able to absorb polar materials, which are widely used in the purification of sugar water, alcohol, formaldehyde, and exhaust gas.

Conflict of interest

I declare that I have no conflict of interest with respect to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has data included as electronic supplementary material.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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