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Activated carbon air filter and rubber seed oil approach from waste rubber seed shell for alternative fuel and improving air quality

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Abstract
Research related to rubber seed conversion to oil and activated carbon as filter media requires further exploration. Therefore, the main objective of this study to investigate the rubber seed oil as alternative energy and rubber seed Shell Activated Carbon (RSSAC). Thermo-chemical method conducted with separation process between the kernel and the shell. The process used temperatures of 550 and 600°C. Biodiesel was produced by a blending process using a frequency of 20kHz, temperature of 60°C and 2h holding time. In addition, the side product was converted into activated carbon through carbonization and activation using KOH. Air filter fabricated using three layers, where the top and bottom layers being non-woven and RSSAC in the middle. It compacted using hot-press method at temperature of 150°C for 60 s to produce an air filter media thickness of 3–5mm. The results show that there are several high compound concentrations i.e. CH_4, aldehydes, and ketonestone. Several gases evolve, such as CO_2, CO, CH_4, H_2O, ketone aldehyde, and HC. Microstructure analysis using Scanning Electron Microscope (SEM) of RSSAC shows that element C significantly increase up to 80%, while O, K, and Ca decreased up to 72%, 66% and 90%, respectively. RSSAC has a large surface area of 175.95m^2/g, and it will have high effectiveness in improving indoor air quality (IAQ). This is indicated by the result of IAQ analysis where the humidity, temperature, CO, CO_2, TVOC, and PM_{10} were lower than the acceptable limit of 70%, 27°C, 1000ppm, 10ppm, 3 ppm, and 0.15 mg/m^3, respectively.

Keywords:
Activated Carbon;
Air Quality;
Alternative Fuel;
Rubber seed;
Waste material;

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INTRODUCTION

Biofuels have attracted significant interest because of the plentiful supply of feedstocks [1]. Different raw materials, such as vegetable oil, rice husks, sawdust, wheat stalks, sugarcane bagasse, algae, de-oiled cake, and oilseed shells, can be used for this purpose. Research has been conducted on utilizing agricultural waste, such as non-edible oil seeds, for biodiesel production [2, 3, 4, 5]. In addition to producing biodiesel, non-edible oil seeds can be used as feedstocks to create valuable products and fuels using biochemical and thermochemical conversion methods [2]. Thermochemical techniques encompass various processes, such as incineration, gasification, combustion, carbonization, and pyrolysis [6]. The pyrolysis process provides benefits such as low temperature, absence of oxygen, increased yield and quality of liquid products, improved control of valuable chemical production, and safe storage and transportation [7]. During pyrolysis, biomass changes into liquid, gas, and char products at temperatures between 300 and 700°C without the presence of oxygen is required for breathing. Approximately 25–70% of the liquid product yield can be achieved from seeds that contain oil.

The research regarding on rubber seed oil production was conducted by [6], they found that the maximum oil produced is 0.45g oil/g kernel using soxhlet extraction using n-hexane as electrolite. While using mechanical press, it can produce 0.28g oil/g kernel [8]. Moreover, 0.21-0.34g oil/g kernel can be produced using supercritical Carbon dioxide [9]. In other hand, the combination methods between mechanical press with n-hexaneable to produce 0.49g oil/g kernel [7]. However, the method and parameter potential to enhanced by appropriate temperature and combination of pyrolysis and mechanical press to maximize the oil content per kernel.

Rubber seeds, a potential non-edible source, have a kernel comprising 52–60% of their weight, and the oil extracted from this kernel is suitable for producing biodiesel. Rubber seed is a hard by-product derived from the rubber tree, known as Hevea Brasiliense, found mainly in tropical regions and grown extensively for its latex, which is used as a natural rubber source. India is one of the top five nations in rubber seed production, following China, Malaysia, Thailand, and Indonesia. In a previous study [8], rubber seed kernels were used to create biodiesel, which was then examined in an internal combustion engine. Using the shell part of the rubber seed (RSS) as a biomass feedstock can provide advantages and the potential to address existing environmental issues, energy shortages, and support the sustainability of biodiesel sectors. The shell of a rubber seed comprises 40–48% of its weight. Direct pyrolysis is advantageous because the shell has a lower oil content than the kernel. The use of oil seeds and seed shells in pyrolysis to produce valuable products has been documented. Previous study [9] investigated the production of activated carbon from rubber seed shell through physical activation using steam. The research showed that rubber. The seed shell is an excellent source of raw material for making high-capacity activated carbon through physical activation with steam. Other previous researcher [10] studied the pyrolysis of pomegranate seeds and found that the liquid yield reached a maximum of approximately 54wt% at two different temperatures: 500 and 600°C.

Pollution-induced environmental degradation has escalated rapidly and is viewed as a catastrophe. Different types of pollution, such as air, water, and toxic/chemical waste, are responsible for health problems, environmental destruction, and hindering industrial growth and economic progress. The crucial role of indoor air quality in the advancement of society has been highlighted by various researchers [8, 11, 12, 13]. Indoor air quality is typically contaminated, with pollution levels determined by the activities performed, emission sources, and equipment used. Atmospheric pollution can occur in the form of either particles or gases. Indoor and outdoor air quality are affected by different environmental factors. Pollution comes from different sources, such as outdoor and indoor sources. Hence, it is crucial to ensure indoor air quality for a sustainable and healthy lifestyle [8][12]. Recently, Malaysia implemented regulations regarding indoor air quality for public use [14].

Numerous studies have investigated indoor air quality, categorizing it into two groups: public/commercial buildings and industrial settings [9, 15, 16, 17, 18, 19, 20]. Previous study [9] highlighted that inadequate ventilation systems are the main cause of high levels of pollutants found in public buildings. However, a survey of commercial buildings found significant Sick Building Syndrome (SBS) symptoms, including fatigue, dizziness, and headaches. In an industrial setting, the indoor air is typically contaminated with various pollutants based on the activities taking place, where the emissions originate, and the equipment being used [19]. Hence, to reduce the decline in IAQ, industry management should offer engineering controls, IAQ management programs, and training and education for employees [20].

Typically, indoor air pollution levels are higher than outdoor levels because of emissions from human activities, building materials, furniture, carpets, paints, and cleaning products [21]. Hence, maintaining indoor air quality is essential for creating a sustainable and healthy environment [8]. According to [22, 23, 24] various techniques are used to manage indoor air pollution, such as ventilation and air purification methods. The effectiveness of Mechanical Ventilation and Air-Conditioning (MVAC) systems in decreasing indoor particulate levels has been scientifically demonstrated. Nonetheless, this method does not guarantee a reduction in harmful gases; in reality, it requires additional energy [25]. The most prevalent method for cleaning air, particularly for volatile organic compounds and other contaminated gases, is activated carbon

[26]. Various adsorption materials, such as ACF, silica gel, zeolite, alumina, and GAC, are currently available in the market. Some studies have shown that temperature and humidity levels in actual buildings can vary greatly throughout different months, seasons, and years, regardless of their specific conditions [13][27]. However, there has been no scientific assessment of the filters on the market, meaning that actual VOC pollutants in real buildings remain undocumented [13].

According to various researchers above that there are several gaps that potential to explored such as in optimum methods to produce the rubber seed oil which is lower than 50% per g kernel. Through the combination of pyrolysis and mechanical press it believes could produce more than 50% per g kernel. In addition, the existing filter still using charcoal that has lower specific surface area compare with activated carbon (charcoal that activated) which cause the Rubber Seed Activated Carbon (RSSAC potential to increase the absorption capacity of the air pollutants. Therefore, the main objective of this research is to produce rubber seed oil using combination of pyrolysis and mechanical press and produce RSSAC as filter media to improve Indoor air quality

METHOD

Prior to pyrolysis process, the separation between the kernel and the shell conducted to produce two different products which are fuel and activated carbon, respectively. The pyrolysis process was conducted in atmospheric condition, 100 g kernel put into the camber with n-hexane electrolyte. This process operated with temperature of 550 and 600°C with heating rate of 10 and 40°C/minute as well as 1 hour holding time. The residue of the kernel will continue processed by mechanical press. The thermal decomposition characteristics of rubber seed shell (RSS) were analyzed using a TG analyzer (Netzch STA449F300) over a temperature range of 30–800°C with a heating rate of 20°C/min in a nitrogen atmosphere (99.9% purity) at a flow rate of 60 ml/min. Ten milligrams of RSS was subjected to a programmed TG condition, and the resulting gaseous products were consistently monitored and measured using a coupled FTIR system.

The activation procedure was carried out using a furnace, followed by crushing the RSS charcoal into powder and sieving it to a particle size ranging from 0.25 µm to 1 mm. During this period, the charcoal was immersed in a crucible containing a specific chemical agent (KOH) with a known concentration for activation. The ratio of RSS to the chemical solution was 1:1. The chemical substance was mixed with distilled water, heated to 60°C, and stirred to create a fully blended electrolyte. The mixture of RSS and KOH electrolyte was immersed for a 24-hour. Subsequently, the materials were cleaned with water to neutralize their pH and heated in a furnace at 850°C for 1 h in an oxygen-free environment to enhance their surface area for adsorption applications. The activated charcoal was then cooled to ambient temperature.

A Scanning Electron Microscope (SEM) was used to visualize the porous structure of the materials by scanning the specimen with a high-energy electron beam to produce images. Electrons generated from the electron gun were focused using magnetic condenser lenses, which controlled the electron trajectory. During the experiment, samples were placed in a chamber and exposed to the electron beam, generating signals such as secondary electrons, back-scattered electrons, photons, visible light, and heat. The detectors captured the secondary electrons to produce surface images on the monitor. The process was carried out in a vacuum chamber at a pressure below 5 Pa for 60 s. Cross-sectional analysis was conducted at 1000X magnification using 15 kV, a probe current of 50, and a working distance of 15 mm.

Air Filter Development

Figure 1 shows the non-RSSAC and RSSAC air filters used to cleanse the outside air entering the building. The filter measured 60 cm × 30 cm × 2.5 cm (length × width × height). The RSSAC air filter was created using filter paper containing RSSAC embedded within the paper. A rectangular RSSAC was installed in the central air-conditioning system, allowing air to enter the building. The purpose of installing this filter in the selected buildings was to examine how effectively the RSSAC filter reduces air pollutants. Various air pollutants, including CO, CO_2, TVOC, and respirable particulates, must be eliminated to ensure that they remain within the acceptable limit set by DOSH in 2010.

RESULTS AND DISCUSSION

Chemical composition of rubber seed oil

The compositions of the liquid samples were established by analyzing the relative peak areas of the identified components in the chromatograms obtained from the GC-MS analysis (Table 1).

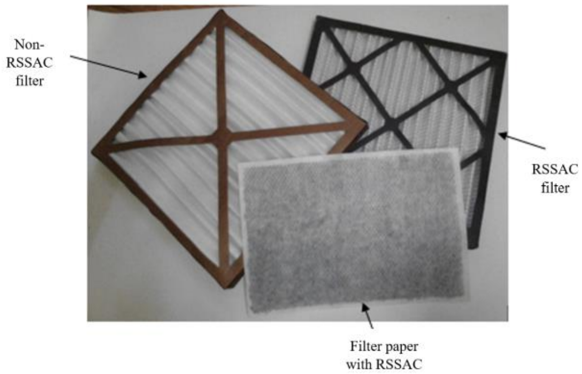


Figure 1. RSSAC and non-RSSAC air filter

The most prevalent organic products identified were acetic acid, phenolic compounds, creosol, pilocarpine, benzene, 3-Hydroxy-4-methoxybenzoic acid, levoglucosan, and Studies have also documented the existence of oxygenated aromatic compounds such as acids, phenols, and creosol in the liquid samples derived from pyrolyzing shell and cake [1, 6, 28]. During the pyrolysis of RSS, hemicellulose undergoes deacetylation and cleavage, resulting in the production of acetic acid and water. Higher pyrolysis temperatures resulted in the presence of major phenolic compounds, such as phenol, 2-methoxy-, phenol, 2, 6-dimethoxy-, and phenol, 4-ethyl-2-methoxy-, and small amounts of other phenolic compounds. The decomposition of lignin is responsible for these results [29][30].

Moreover, the presence of creosol suggests that a section of lignin has undergone decomposition. Based on GC-MS analysis, pilocarpine, a nitrogen-containing organic compound, was detected, which can be attributed to the moderate temperature around 250-300 °C used during pyrolysis to avoid the degradation analytes and efficient separation [6]. During decomposition, the chemical bonds within the lignin structure, ether and carbon linkages are broken, releasing smaller aromatic compounds. In thermal decomposition in temperature of 450 °C and above, guaiacyl units degrade to form intermediate compounds like guaiacol, which can then undergo methylation or structural rearrangement to form creosol. Therefore, the detection of creosol in a sample provides strong evidence that lignin has been broken down and that guaiacyl-type lignin components were present. Table 1 demonstrates that the liquid product, which has a high phenolic compound content (it contains ≥30% from total relative peak area (%)), is suitable for producing resins, surfactants, and antioxidants through biochemical processes [29][30]. The liquid product can also be used as a source of hydrocarbons to produce valuable chemicals such as ethyl vinyl, resins, and adhesives [29].

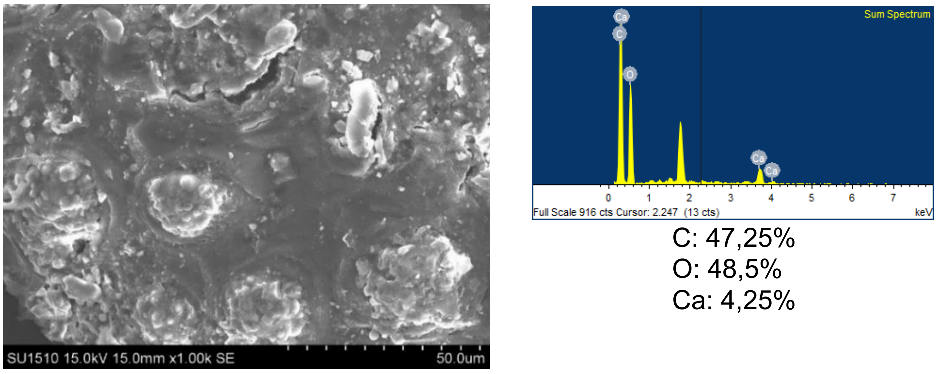
Table 1. Chemical composition of rubber seed oil

Various pyrolisis Temperature (°C)	**350**	**400**	**450**	**500**	**550**	**600**
Compound	**Relative peak area (%)**					
Acetic Acid	2.55	5.36	5.16	12.8	10.24	13.9
Acetic Acid, (acetyloxy)-	-	0.71	0.89	2.55	1.9	2.97
1-Nitro-2-propanone	-	0.2	0.25	0.6	1.17	1.71
Pilocarpine	-	0.58	0.77	2.01	1.93	3.15
Phenol	0.45	-	0.19	0.7	1.08	1.17
1,2-Cyclopentanedione, 3-methyl-	-	0.35	0.48	2.15	1.94	1.91
Benzyl alcohol	-	0.03	0.18	0.98	1.08	0.97
p-Cresol	-	-	0.24	1.13	1.73	1.51
Phenol, 2-methoxy-	-	1.68	2.61	7.59	6.88	6.95
Phenol, 3,5-dimethyl-	-	-	-	0.32	1.0	0.76
Creosol	-	1.74	2.89	11.7	15.01	11.3
1,2-Benzenediol, 3-methyl-	-	0.13	0.26	0.27	1.43	0.55
1,4-Benzenediol, 2-methoxy-	-	0.13	0.26	1.44	2.56	1.07
Phenol, 4-ethyl-2-methoxy-	-	1.08	1.38	2.63	3.95	2.5
1,2-Benzenediol, 4-methyl-	-	-	-	1.96	2.94	1.69
Phenol, 2,6-dimethoxy-	-	1.47	1.71	6.18	7.58	4.8
Benzaldehyde, 3-hydroxy-4-methoxy-	0.4	0.36	0.43	2.83	2.28	1.42
Ethanone, 1-(2,3,4-trihydroxyphenyl)-	-	1.12	1.32	4.26	5.92	3.21
Eugenol	-	0.2	0.41	1.24	4.25	1.03
Levoglucosan	-	0.56	5.0	10.7	13.17	8.75
Benzene, 1,2,3-trimethoxy-5-methyl-	-	0.63	0.64	1.65	3.1	1.30
2-Propanone, 1-(4-hydroxy-3-methoxyphenyl)-	-	0.55	0.72	2.61	3.5	2.06
Diphenyl sulfide	-	-	-	1.53	0.03	0.69
Homovanillic acid	-	-	0.62	0.68	1.35	0.65
Phenol, 2,6-dimethoxy-4-(2-propenyl)-	-	0.23	0.56	0.73	2.56	0.56
Xanthoxylin	-	-	0,23	0,72	0,86	0,55
Glycoldial, bis-O-Pentafluorobenzyloxime	-	-	0,21	0,44	0,57	0,36

Microstructure and composition analysis

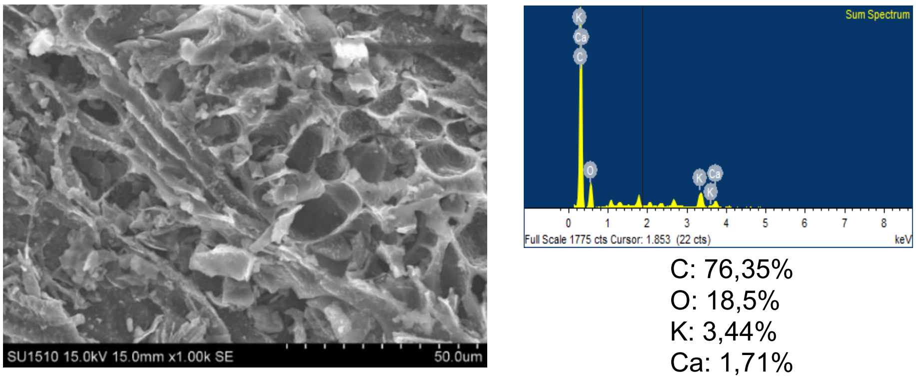
The microstructure of the raw rubber seed shell is shown in Figure 2. The image was enlarged 1000X using the High Vacuum mode and Secondary Electron as the image detector for this characterization. Figure 2 shows the surface characteristics of the raw material, which displays an uneven surface without any visible pores. However, it had low porosity, as indicated by the analysis, showing that the raw material had less porosity than RSSAC. The raw material exhibited a porosity of 1.59%, whereas the RSSAC chemical exhibited the highest porosity of 89%.

The RSS Charcoal began to exhibit increased porosity levels, surpassing those of the original material, as shown in Figure 3. Additionally, it had an uneven surface with small flakes. The presence of K in the composition analysis was a result of the indirect carbonization process. The immersion of K content 3.44wt.% within the samples resulted in a notable enhancement in the porosity of RSS Charcoal. A porosity enhancement of 44.41% was observed, surpassing that of the raw material. The C content increased by 76.35 wt.% compared to the raw material, and the O content was low at 18.5 wt.%, which was caused by its reaction (dehydration and decarboxylation) with hydrogen to produce H_2O during the carbonization process.



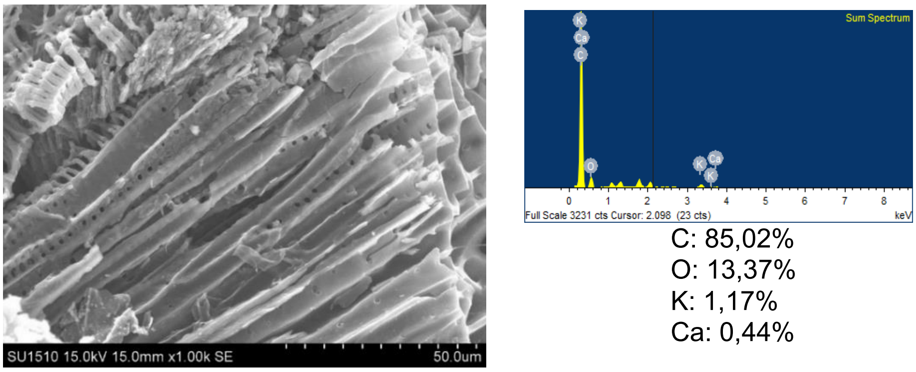
C: 47,25%
O: 48,5%
Ca: 4,25%

Figure 2. Microstructure and composition of raw material



C: 76,35%
O: 18,5%
K: 3,44%
Ca: 1,71%

Figure 3. Microstructure and composition of rubber seed shell charcoal



C: 85,02%
O: 13,37%
K: 1,17%
Ca: 0,44%

Figure 4. Microstructure and composition of RSSAC

The Ca content of RSS Charcoal was 6.35 wt.%, which was higher than that of the raw material. Elevated calcium levels increase the likelihood of reacting with oxygen to produce calcium oxide, which serves as a valuable industrial tool [31].

The RSSAC sample is shown in Figure 4. The outcome of the procedure displayed a fully formed honeycomb shape, which was designated as a porosity indicator. The increased porosity of RSSAC suggests that it has a greater capacity for adsorbing air pollution than raw RSS and RSS charcoal. Therefore, this function was utilized as an air filter in the air-conditioning system used in the designated structures. The honeycomb structure with the highest carbon content of 85.02wt% showed that the activation process effectively increased the carbon content in the RSS. To enhance carbonization, the initial burning process was followed by a died process involving chemical activation to eliminate oxygen from the carbon skeleton and interact with hydrogen. Therefore, the C content in RSSAC was higher than that in both the raw material and RSS charcoal. This finding may be associated with the breaking of C–O bonds on the carbon surface during oxidation [28][31].

IAQ and Dust Analysis before PSAC Air Filtration

The RSSAC air filter was created and utilized to test its ability to remove or reduce air contaminants. When evaluating effectiveness, IAQ was assessed with standard air filtration in an IAQ chamber room, adjusting the ratio to meet ASHRAE standard 55 at 0.2, and providing 12 L/s/p of fresh air. The IAQ monitoring system was conducted for a period of seven days within the hours of 8:00am to 5:00pm. During the surveillance, the levels of relative humidity (RH), temperature, CO_2, CO, TVOC, and PM_{10} were measured, and the findings are displayed in Figures 5–10. The RH and temperature were also monitored, and the results are displayed in Figure 5 and 6, respectively. The outcome indicated that the RH value was below the limit of 70% [23]. Nevertheless, the day seven monitoring revealed that the RH exceeded the acceptable limit, registering 71.04%. Temperature monitoring showed temperatures ranging from 20.2 to 25.6 °C, which is below the acceptable limit of 27°C set by the ICOP IAQ.

The relationship between RH and temperature when using a conventional filter in the chamber indicates that when RH increased, the temperature decreased.

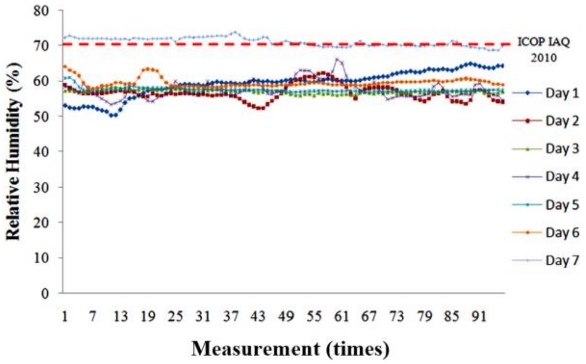


Figure 5. Relative humidity with conventional air filtration

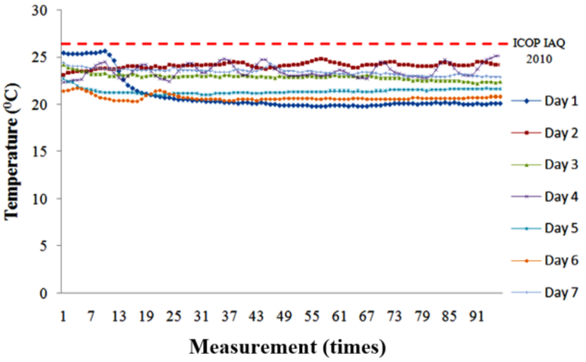


Figure 6. Temperature with conventional air filtration

The increase in humidity was a result of inadequate airflow caused by the current air-conditioning system. Therefore, the temperature increased slowly. The CO_2 and CO levels were tracked in the chamber room using an IAQ meter for a week, as depicted in Figure 7 and 8. The levels of CO_2 and CO were below the respective maximum limits of 1000 ppm and 10 ppm. This is evident because the chamber room felt comfortable with the right number of people and minimal carbon monoxide effects. The concentrations of CO_2 and CO ranged from 415 to 618ppm and 1.9 to 4.6ppm, respectively.

The CO_2 in this room originated from human and plant breathing, as well as electricity usage. Restricting the use of fossil fuels as the primary source of CO_2 emissions resulted in a CO_2 concentration below the acceptable limit set by the ICOP-IAQ in 2010 [23]. The level of CO_2 in the chamber was determined by the amount of fresh air required to meet the acceptable IAQ limit while minimizing energy usage. In this study, an air damper was used to regulate a ratio of 0.2. This proportion was chosen according to ASHRAE standard 55 for the air turnover rate in office buildings. During the experiment, the airflow was set to 12 L/s/p.

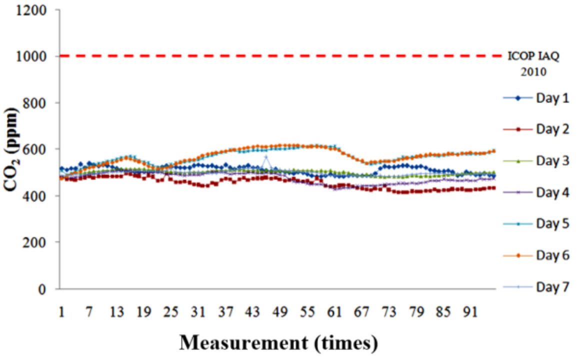


Figure 7. CO_2 concentration with conventional air filtration

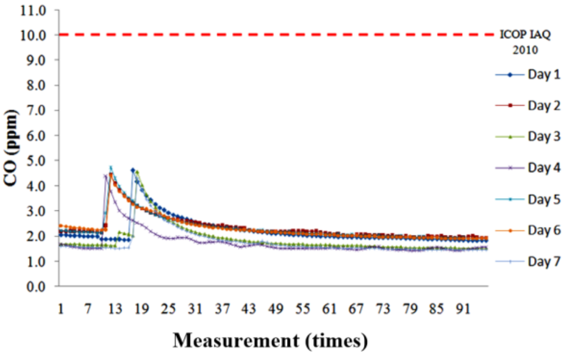


Figure 8. CO concentration with conventional air filtration

Furthermore, CO emissions were below the acceptable limit because there were few sources in the chamber room, such as printers, furnaces, stoves, ovens, and water heaters. The CO levels increased notably between measurement time of 10-13 on days 2, 4, and 5, and between measurement times of 18 to 19 on days 1, 3, and 7. This was accompanied by a gradual decrease in CO levels, which was believed to be caused by a limited supply of CO in the chamber.

The TVOC and PM_{10} levels, according to the [23], were set at 3 ppm and 0.15 mg/m^3, respectively. The TVOC levels from day 1 to 7 remained below the acceptable limit, with readings ranging from 0.1–1.9 ppm. On all days except Day 1 and Day 6, PM_{10} concentrations exceeded the acceptable limit. The PM_{10} levels on these two days were below the permissible threshold, as indicated by the measurement time of 25 to 96 times.

The reason for the low TVOC value in this room was that it was old and did not have many sources of TVOC emissions, such as paint, aerosol spray, and wood preservative. The presence of smoke, dust, salt, acid, and metal in the chamber was responsible for the elevated PM_{10} concentration. The RSSAC filter eliminates the potential for emissions. This study focused on creating an RSSAC filter to reduce the release of pollutants that can harm human health, cause issues such as asthma, bronchitis, and other respiratory diseases, as well as impacting the immune system. Figure 9 and Figure 10 display the levels of TVOC and PM_{10} in the chamber room over a period of seven days.

IAQ and Dust Analysis after RSSAC Air Filtration

The IAQ monitoring results in the chamber with a standard air filter revealed elevated PM_{10} levels that may impact human health. Hence, in this study, an RSSAC air filter was developed to eliminate or decrease PM_{10} levels and other harmful pollutants. The analysis results indicate that RSSAC is a suitable choice for the continued development of air filters. The filter was 60cm long, 30cm wide, and 2.5cm high. The experimental setup adhered to ASHRAE Standard 55 with a 0.2 ratio and a fresh air change rate of 12 L/s/p. The observation was carried out for a week, from 8.00 am to 5.00 pm each day (during working hours). The process of monitoring IAQ included examining RH, temperature, CO_2, CO, TVOC, and PM_{10}, and the findings are displayed in Figures 11–16.

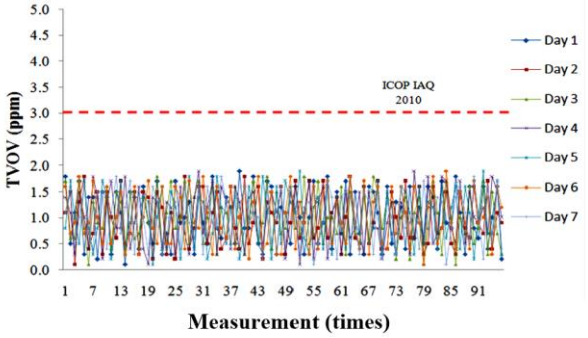


Figure 9. TVOC concentration with conventional air filtration

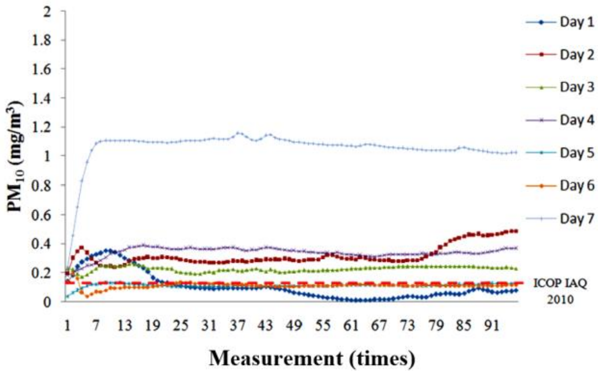


Figure 10. PM_{10} concentration with conventional air filtration

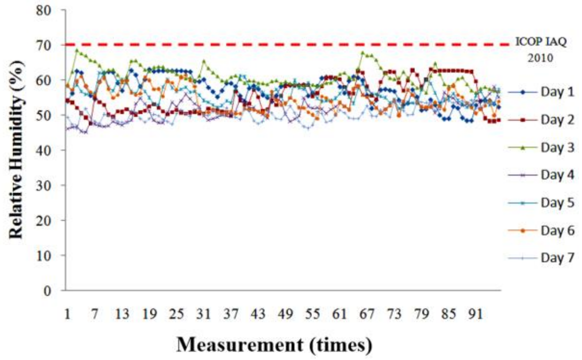


Figure 11. Relative humidity after RSSAC air filtration

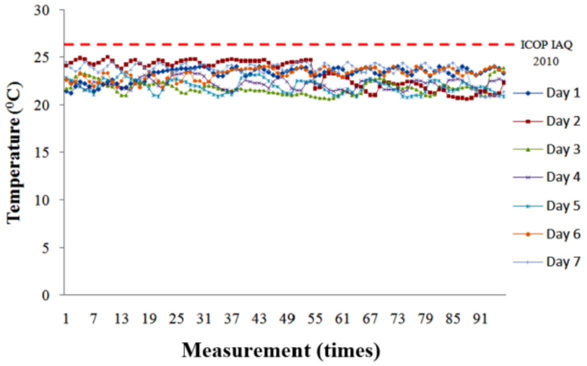


Figure 12. Temperature after RSSAC air filtration

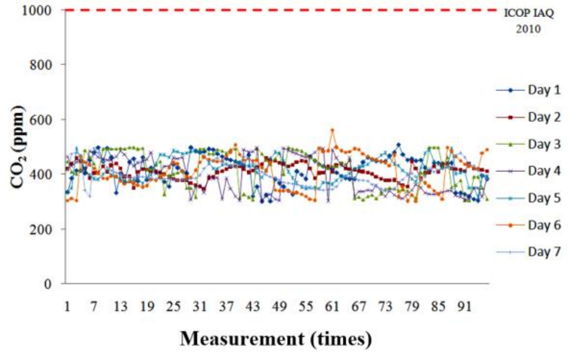


Figure 13. CO_2 concentration after RSSAC air filtration

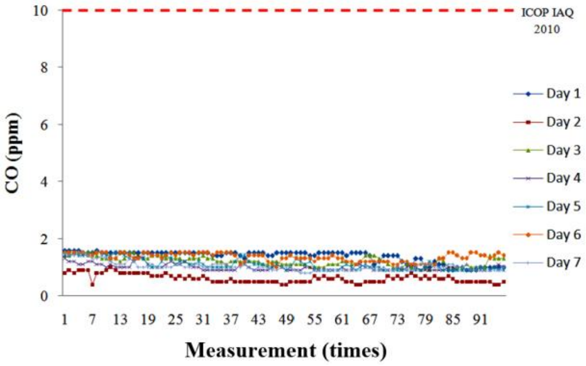


Figure 14. CO concentration after RSSAC air filtration

There is a clear relationship between RH and temperature, with RH decreasing as the temperature increases and vice versa. The study found that the relative humidity (RH) and temperature were within the normal range, ranging from 45.1 to 66.9% and 20.1 - 24.9°C. Therefore, the findings indicate that the RH and temperature were below the acceptable limits of 70% and 27°C.

The presence of an HVAC system in the room had a significant impact on both low and high humidity and temperature levels. Dehumidification occurred due to a rise in temperature when the HVAC system was absent. This phenomenon had an indirect impact on the increase in other emissions. The temperature decreases following RSSAC air filtration ranged from 20.1 - 24.9°C, whereas with a conventional air filter, it ranged from 20.2 - 25.6°C. Therefore, the RH value fell below the allowable limit of 70%. It can be inferred that the RH and temperature were at comfortable levels.

Figure 13 and 14 display the CO_2 and CO pollutants after the RSSAC air filtration process. The CO_2 concentration decreased after using the RSSAC air filter, decreasing from 415–618 ppm to 302–563 ppm. In addition, the CO concentration decreased by 0.4–1.5 ppm following the use of the RSSAC filter, compared to the initial levels of 1.9–4.6 ppm. Therefore, these findings suggest that the RSSAC air filter effectively filtered outside air and enhanced the amount of fresh air entering the building. The increment of absorption capacity is caused by huge pore of the RSSAC which can absorb more C-O content [6][9].

Figure 15 and 16 show the TVOC and PM10 levels after using the RSSAC filter. The reduction in both parameters indicates improved IAQ with the RSSAC air filter. TVOC levels decreased to 0.1–0.49 ppm from the initial range of 0.1–1.9 ppm. PM10 levels also decreased to 0.02–0.216 mg/m³ compared to the initial levels of up to 1.15 mg/m³. The RSSAC air filter effectively reduced TVOC and PM10 levels due to its high efficiency.

Nevertheless, a high density of PM10 was observed during the assessment, although it remained below the permissible threshold of 0.15. Overall, PM10 levels stayed within the allowable limit. The increased absorption of TVOC and PM10 by RSSAC was influenced by the attractive force between VOC molecules and RSSAC's large surface area. In addition, the RSSAC filter produced lower temperature and humidity, reducing kinetic energy and increasing pollutant trapping time [13][23].

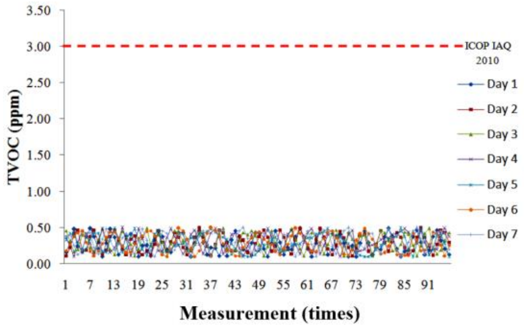


Figure 15. TVOC concentration after RSSAC air filtration

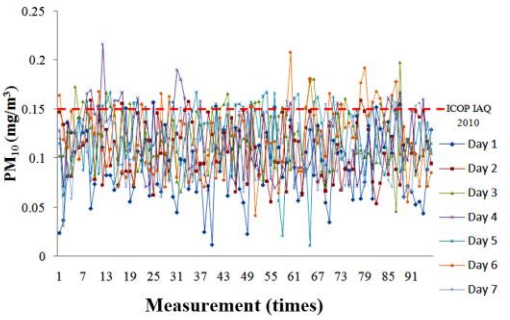


Figure 16. PM_{10} concentration after RSSAC air filtration

The monitoring of the RSSAC air filter's IAQ revealed its effectiveness in enhancing chamber IAQ by reducing temperature, boosting humidity, and lowering levels of CO_2, CO, TVOC, and PM_{10}. The RSSAC filter is the best choice for enhancing indoor air quality in buildings and the final effect is human health improvement.

CONCLUSION

Rubber seed oil and air filters from RSSAC have been produced, and they are promising alternative fuels for improving air quality by reducing harmful exhaust gases. In addition, the air filter from RSSAC is more effective than the conventional air filter. Conventional air shows that there is one day data of Humidity is exceeding the limit of 70% and most of the PM_{10} is exceed 1.15 mg/m^3. The air filter RSSAC met the standard regarding humidity and temperature below 70% and 27°C, reduce the CO_2 from a maximum of 618 to 563 ppm, and reduced the CO emission from a maximum of 4.6 to 1.5 ppm. The powerful air filter from RSSAC was also demonstrated by the reduction in TVOC and PM_{10}. The maximum TVOC value by the conventional air filter was 1.9 ppm, and it was reduced to 0.49 ppm by the air filter RSSAC. Moreover, PM_{10} also meets the standard by RSSAC filter success to reduce from 1.15 to 0.216 mg/m^3.

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