UNIVERSITI TEKNOLOGI MARA

PROSIDING



Seminar INSIGHTS 2002
Universiti Teknologi MARA

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UTILISATION OF GAS FUEL IN CHARCOAL ACTIVATION PROCESS

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ABSTRACT

Palm oil mills form an essential part of the palm oil industry. The palm mesocarp fibre, palm shells and empty fruit bunches (EFB) are abundantly produced as wastes by the milling process of palm oil mills. Due to the availability of these wastes, the oil palm shell is used as a raw material to produce activated carbon. A batch-process, self-burning kiln was built to produce charcoal from palm shell. The design of the kiln was based on the traditional method of charcoal manufacturing. The operating parameters of the carbonisation process were carbonisation time, the air flow rate and the carbonisation temperature. The charcoal was then activated in a reactor, which was made from a stainless steel column of 10 cm ID and 30 cm high. Liquefied petroleum gas (LPG) was used as a fuel to supply energy during the activation process. The gaseous products of combustion, mainly carbon dioxide and water vapour, were routed to the charcoal bed at the bottom of the reactor to mix with steam and air, which were supplied from their respective sources. The gaseous mixture was then used as the activating agent during activation. The operating parameters of activation were activation time and activation temperature. The quality of the charcoal and activated carbon produced was determined in terms of their surface areas and pore volumes. The activation process using the charcoal produced by the kiln successfully yielded a high porosity activated carbon.

INTRODUCTION

Activated carbon, due to its large surface area and porosity, has been widely used for the adsorption of pollutants from gaseous and liquid streams, for recovery of solvents, as a catalyst or catalyst support (Mattson et al., 1971; Cheremishinoff & Eclerbusch, 1978). It has been industrially manufactured from various raw materials such as bituminous coal, pine wood and coconut shell (Hassler, 1974). There are various processes and methods used for the production of activated carbon, which include rotary kiln, shaft kiln, multiple hearth furnace and fluidised beds. Though widely employed, rotary kilns are energy intensive with poor gas-solid contact. An excellent gas-solid contact and high heat and mass transfer rates can be achieved by using fluidised-bed reactors. However, fluidised-bed reactors have not received much attention for the activation of carbon. Since the production of activated carbon involves gas-solid non-catalytic reaction, the design of a reactor should consider a good contact between the gas-solid phases and good transport processes.

The principle properties of manufactured activated carbons depend on the type and properties of the raw materials used. Almost any carbonaceous materials of animal, plant, or mineral origin can be converted to activated carbon by proper processes. From the economics point of view, the selection of raw material should be based on several factors. Firstly are the raw material volume and cost, availability, storage life, and workability. Secondly, a low inorganic content is necessary, so that the chemical constituents of the raw material are volatilised

during the carbonisation and activation processes so yielding a porosity of the product. High density of the raw material contributes to enhance the structural strength of the carbon and hence, it can withstand excessive attrition during use. Volatile content together with density contribute to different properties of the final product. Raw materials with low density and high volatile matters, eg. wood and lignin, produce activated carbon with large pore volume but low density (Bansal et al., 1988). In the Western world, most activated carbons are produced from coal, both bituminous and anthracite, owing to its low volatile content which gives a high yield (Reupke et al., 1992). In the developing countries, a major consideration is based on the availability of the raw materials, such as coconut shell, wood and rice husk. Despite having high volatile matters, these materials are inexpensive and thus, the economics related to their use are often favourable (McDougall, 1991). Coconut shell, fruit pits and other nut shell produce hard, granular carbons with large micropore volume and these carbons are suitable for adsorption in vapour and liquid. With respect to palm shell, the review by Reupke et al. (1992) indicates that the material is readily available and extremely cheap. According to Chan et al. (1976), Yunus (1995), Wan Daud (1996), Hussein et al. (1996) and Abdul Rahman (1998), it is possible to produce a good quality activated carbon from palm shell. However, the properties of commercial palm-shell-based activated carbon are not available for comparison to other activated carbons.

RESEARCH OBJECTIVE

In this work, a batch-process, self-burning kiln was built to produce charcoal from palm shell. The charcoal was then activated in a fluidised-bed reactor using a gaseous mixture of carbon dioxide, steam and air as the activating media.

EXPERIMENTAL SECTION

Raw Material

The raw material, oil palm shells of *Tenera* species, was obtained from a local oil palm mill. The shells, after cleaning and dried under ambient conditions, were crushed using a 3-hp screw-type hammer mill which has a discharge outlet equipped with a screen of aperture size 5.5 mm. The crushed shells were then screened to a size range of 1 to 5.5 mm using a mechanical sieve, resulting in about 85% (by weight) of the samples.

Sample Preparation

Self-burning batch process

Preparation of the samples involved two stages, i.e. carbonisation followed by activation. For the carbonisation process, about 50 kg samples of the crushed shells were loaded into the kiln through a loading funnel. The shell was manually ignited using a Liquefied Petroleum Gas (LPG) portable burner through a door at the bottom of the kiln. A sufficient supply of air (0.8 m^3/min) was introduced into the kiln using a 1.5-hp vortex blower from the bottom part of the kiln via a perforated plate. The door was closed when self-burning was observed. A new batch of the crushed shell was then introduced into the kiln. To maintain the carbonisation temperature, the airflow rate was manually controlled by adjusting the valves fitted at the outlet of the blower. The relationship between the airflow rate and the carbonisation temperature in the batch system is shown

in Table 1. Air was consistently supplied at the desired flow rate into the kiln to maintain the carbonisation temperature and was shut off after 5 hours. The carbonisation temperature was set at various temperatures ranging from 300 to 800°C, with an interval of 100 degrees. The time taken for the burning shells to reach the required carbonisation temperature in the batch system is shown in Table 2. The charcoal produced was left for 20 hours in the kiln burning-chamber for natural cooling process. The charcoal was sieved for two size-ranges of 1 - 3 mm and 3 - 5 mm for characterisation.

Table: Relationship between the airflow rate and the carbonization temperature in the batch system.

Carbonisation temperature (°C)	Volumetric air flow rate (m^3/min)	Linear air flow rate (m/min)
300	0.13 - 0.15	1.08 - 1.25
400	0.16 - 0.19	1.33 - 1.58
500	0.20 - 0.23	1.67 - 1.92
600	0.24 - 0.27	2.00 - 2.25
700	0.28 - 0.30	2.33 - 2.50
800	0.31 - 0.33	2.58 - 2.75

Table 2: Time taken for the burning shells to reach the required carbonisation temperature in the batch system.

Carbonisation temperature (°C)	Time (min)
300	83
400	108
500	118
600	126
700	132
800	138

Physical activation procedure

Some trail runs were conducted before starting the activation process in order to ensure a proper activation temperature. This was achieved by manually adjusting the regulator of the LPG container and air supplied to the combustion chamber. To begin the production, an accurately weighed amount of char was loaded into a mesh-sampling container. The sampling container was placed inside the reactor chamber. A mixture of steam and air was preheated by the combustion flame of the LPG in the chamber before being injected into the bottom of the reactor. The products of the LPG combustion i.e. H_2O and CO_2 were mixed with the injected steam and air to form a mixture of activating agents. The amounts of the injected steam and air were measured using steam and air flow meters, respectively. The temperature of the reactor chamber was subjected to the burning degree of the LPG, while the operating mode i.e. fixed bed or fluidised bed was dependent on the combined flow rates of the air, product combustion gases and steam introduced.

Fluidised bed operation

A fluidised bed is a bed condition when the pressure across it remains constant with increasing flow rate of a gaseous agent. The fluidising condition was determined by observing the pressure drop across the bed as the flow rate of the activating agent was increased until a critical point was attained. A critical point is a situation when the pressure drop across the bed remains constant even though the flow rate of the activating agent increases. The condition is a transition between a fixed bed and a fluidised bed and is known as minimum fluidisation condition. The operating velocity of the bed was set to $3U_{mf}$, where U_{mf} is the minimum fluidising velocity. The activation time was set for 120 minutes, while the activation temperatures were maintained at 800 and 900°C, respectively.

Rig/reactor set-up

The schematic diagram of the self-burning kiln is shown in Figure 1. The burning rate can be controlled by airflow rate which was introduced at the bottom part of the kiln through a perforated concrete plate. The hole is 10 mm in diameter and the thickness of the plate is 50 mm. The temperature inside the chamber is monitored by four K-type thermocouples which are installed into the wall of the kiln. Figure 2 shows the layout of the physical activation pilot plant. The activation process can be operated in dual mode i.e. fixed bed and fluidised bed which is determined by the pressure drop across the bed using a manometer. A thermocouple, which is connected to a temperature controller/recorder, is inserted into the activation chamber and is used to monitor the activation temperature. The activation time can be varied in order to get the optimum activation period for the respective temperature.

The reactor is made of stainless steel (310) and has a height of 140 cm and 120 cm wide at the top and 10 cm wide at the bottom. The wall thickness is 0.2 cm and the effective diameter is 9.6 cm. Two cyclones of 20- and 12-cm in diameters, respectively, are arranged in series and are fitted to the reactor to catch fine particles. A stainless steel perforated plate has 3-mm diameter holes and are 5 mm apart from each other. The outside of the reactor is insulated with a 4-cm thick kaowool blanket. A door, which is used for the loading of raw material into the reactor chamber and for unloading of the product, is installed at the bottom part and is located slightly above the perforated plate. A thermocouple is installed at the lower part of perforated plate and is used to monitor the activation temperature. The compartments of the plant are jointed by flanges instead of welding for easy maintenance.

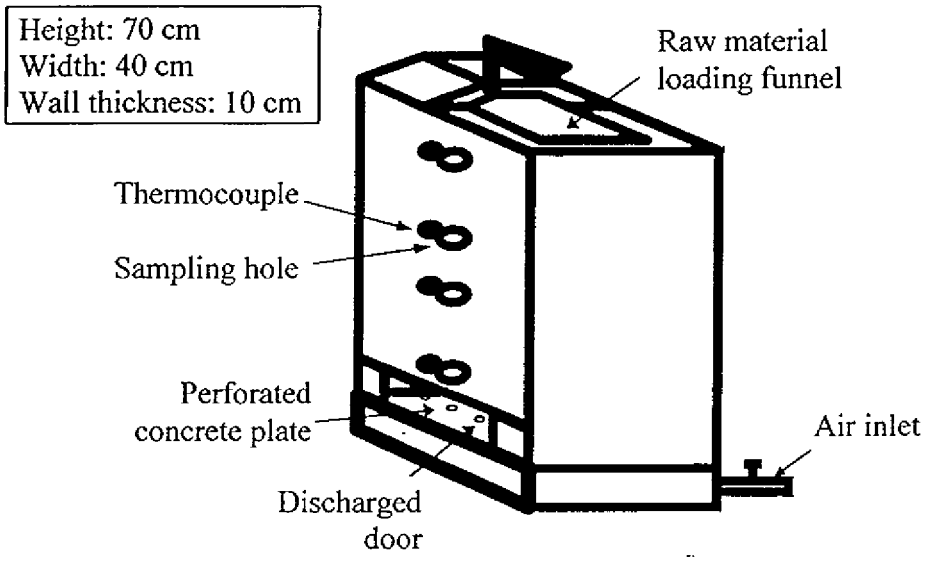


Figure 1. Self-burning system of carbonisation process for oil palm shell.

Characterisation of char and activated carbon

The surface area and volume of the pores of the char and activated carbon were determined by nitrogen adsorption at 77 K using a Micrometics ASAP 2000 porosimeter. The surface area was based on the BET equations which were automatically calculated by the porosimeter. The surface area and volume of the mesopores were determined from the BJH cumulative adsorption data and were calculated manually. From the results, the macropore area was obtained by subtracting the micropore and mesopore areas from the total surface area of the sample. The volume of the macropore was obtained in a similar manner. The BJH method is not valid for the micropore range.

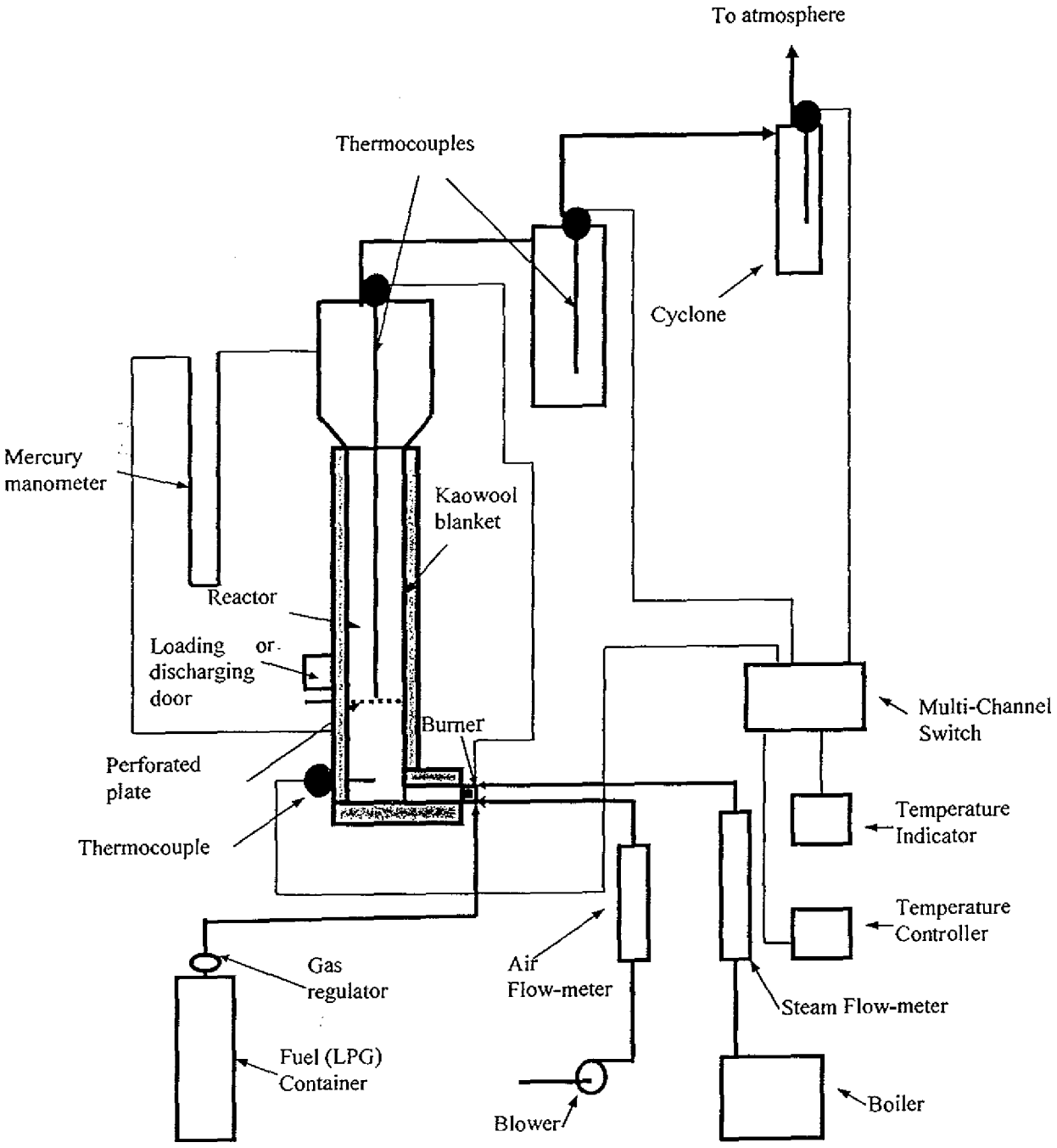


Figure 2 Layout of the activation pilot plant.

RESULTS AND DISCUSSION

Effects of carbonisation temperature on properties of char

Char yield

Figure 3 shows the yields of chars obtained decreased with increasing in the carbonisation temperature. The yields are in general agreement with the results obtained by Wan Daud (1996), Yunus (1995) and Shamsuddin (1992) who produced chars from oil palm shell. Reinoso et al. (1982) and Solano et al. (1982) also obtained approximately the same yields for chars produced from other agricultural by-products. In fact, the figure shows an agreement with the model proposed by Tang et al. (1964). The yield obtained at 300°C was 35.1% and gradually decreased to 24.5% at 800°C. The results are in accordance with the TGA data obtained by Wan Daud (1996) where an increase in the carbonisation temperature from 500°C to 900°C marginally decreased the char yield. In fact, the yield was negligible for a carbonisation temperature of above 700°C.

Based on the TGA for char produced from oil palm shell, dehydration occurred at a temperature below 230°C and depolymerisation occurred in the temperature range of 230 to 400°C (Wan Daud, 1996). Wereko-Brobby (1996) also found that the dehydration stage occurred at temperatures up to 200°C for wood based materials. The next stage was an endothermic process which occurred in the temperature range of 170°C to 300°C; producing pyroligneous liquids and non-condensable gas, mainly CO and CO_2. However, Wan Daud (1996) considered that the transition between dehydration and depolymerisation occurred at a temperature of 230°C for an oil-palm-shell based char. So, the high yield of char at 300°C was due to the remaining of heavier fraction of volatile components in the char. At high a temperature, which is an exothermic process, the bulk remaining of the volatile components of the char were driven off. This stage was orchestrated by the sudden increase in the temperature in the burning chamber due to the heat released during the process. Based on the processes involved in the char production by batch and continuous systems, the heating rate might not be consistent until the final stage of depolymerisation had been achieved.

Surface area

Figure 4 shows the change in the surface area of char produced from the batch system with respect to the carbonisation temperature. The results show that the BET surface areas of the chars for two different size ranges increase with increasing in the carbonisation temperature. These results are different to those obtained by Wan Daud (1996). He reported a lower surface area and this surface area was substantially decreased from 215 m^2/g at 700°C to 60 m^2/g at 800°C. This observation was also confirmed by Christner et al., (1993), Mirasol et al. (1993) and Teranishi et al., (1969).

However, Satya Sai (1997) had shown that the surface area of direct activation of fresh coconut shell using steam and CO_2 increased with increasing in the carbonisation temperature. In other words, the significant increase of the char surface area was due to the application of the activating agents during the carbonisation process. Besides, the carbonisation procedure employed also has a vital impact on the char characteristics. It is believed that the higher surface area obtained in this study is due to the activation gases such as CO_2 and CO

produced by the reaction of the char with oxygen or the oxidation of the volatile components. Also, the utilisation of air might produce localised overheating and so the char produced was not uniform, especially in the fixed bed mode operation. This problem might be solved with a better air distribution in the burning chamber.

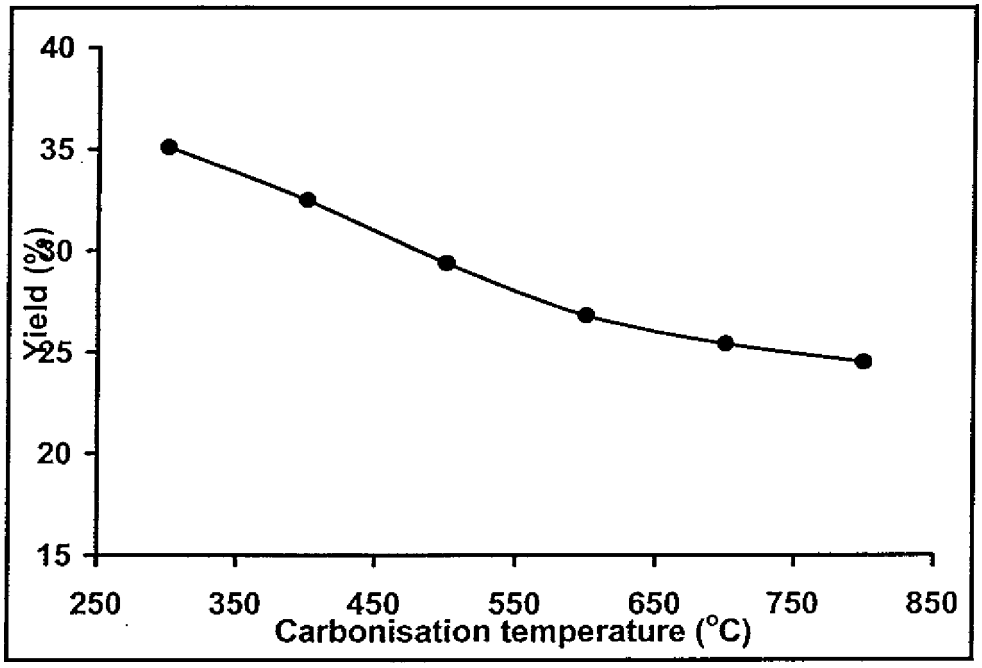


Figure 3: Percentage of char yield versus carbonisation temperature.

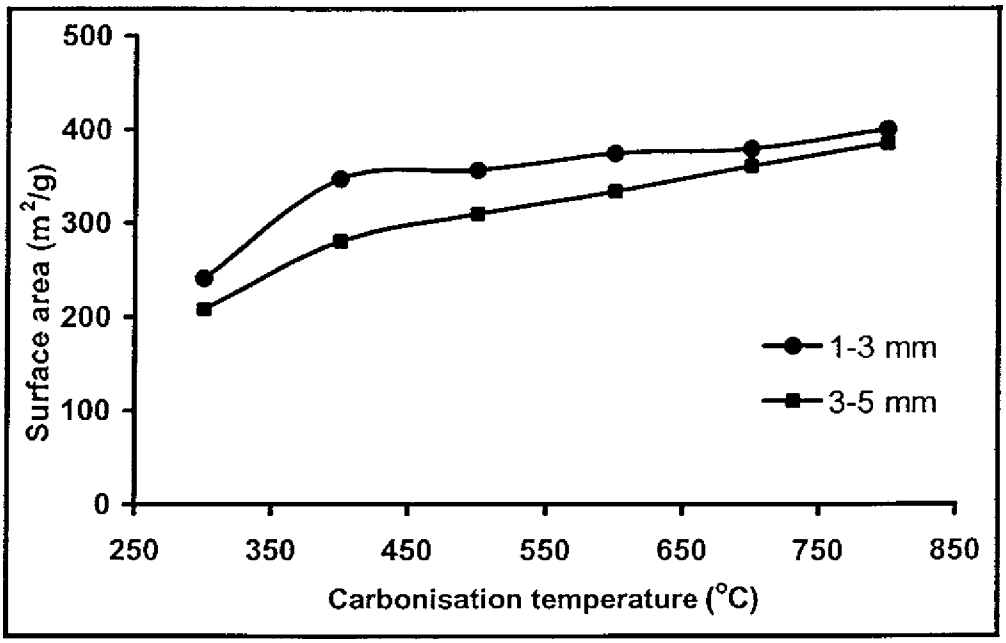


Figure 4: BET surface area of chars versus carbonisation temperature.

Micropore area

The micropore area of the char obtained from the batch system at different carbonisation temperatures is shown in Figure 5. The micropore area increases with increasing in the carbonisation temperature. The increase of the micropore area could be due to the increase in the volume of pores or new pores developed by the volatiles evolved. During the carbonisation process, CO_2 could be formed by the oxidation of carbon elements of the volatile compounds and CO by oxygen from the air supplied. According to Avni et al. (1995), lignin undergoes decomposition, which results in producing CO and hydrogen at temperatures higher than 500°C. Also, according to Williams et al. (1993), rearrangement of the aromatic rings occurs at temperatures above 500°C and will release CO and hydrogen. Thus, at 800°C, besides air activation with fresh char at 300°C to 700°C, there was a possibility of CO_2 activation could have occurred during the carbonisation process which produced a highly microporous carbon. It was found that CO_2 activation occurred at a minimum temperature of 800°C (Wigman 1989, Turkdogan et al., 1969 and Reinoso et al., 1991). The effect of char size on the development of microporosity structure was due to higher heat adsorption by the small size char as compared to the larger size char, which is related to the higher reactivity of smaller particles. However, the larger size (3 - 5 mm) at 800°C achieved a slightly higher micropore surface area. It could be that at a higher temperature, the smaller size char obtained a higher burn out which reduced the microporosity.

Mesopore area

The effect of carbonisation temperature on the mesoporosity of char produced is shown in Figure 6. The mesopore area increases from a temperature of 300°C to a maximum at 500°C before decreasing upon reaching 600°C. This could be due to the enlargement of micropore to mesopore due to the oxidation process. Tomkow et al. (1977) studied the activation of coal at 900°C by steam, CO_2 and oxygen. They found that when using oxygen as the activating agent, activation would only occur at the initial stage of the process. At the latter stages of activation, the micropores are blocked by the surface of the oxygen structures formed at their entrances, causing the interior of the micropores to be inaccessible for further activation. The presence of ash could increase the char reactivity and catalyse the reaction with oxygen.

Macropore area

The effect of carbonisation temperature on the macroporosity of char produced is shown in Figure 7. The area of macropores with radii larger than 50 nm shows a maximum at 600°C for both of the char sizes. The decrease in the development of the macropores could be due to the oxidation of the outer surface of the particles after the beginning of pore development at low temperature. In general, the overall increase in the volume of the macropores between 400°C to 800°C could be due to the marginal development of macropores or enlargement of mesopores. The higher macropore area in smaller particles was due to the higher reaction activity of smaller particles.

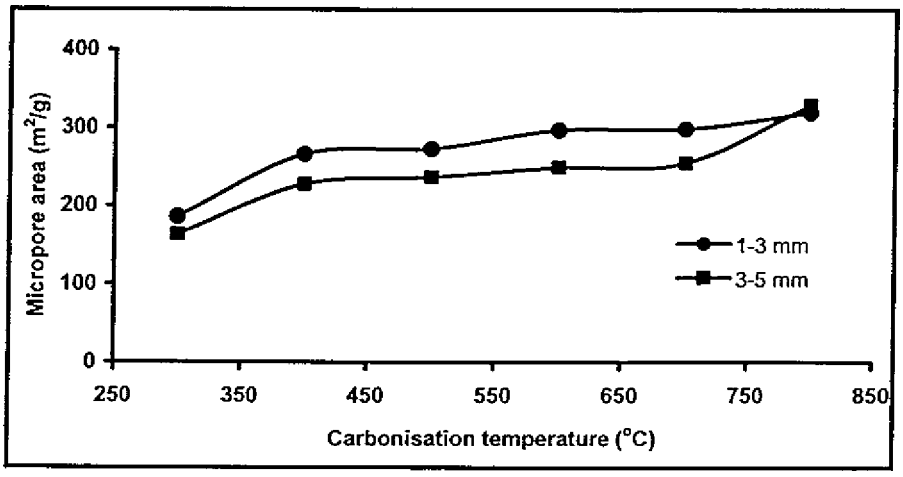


Figure 5: Micropore specific surface area versus carbonisation temperature.

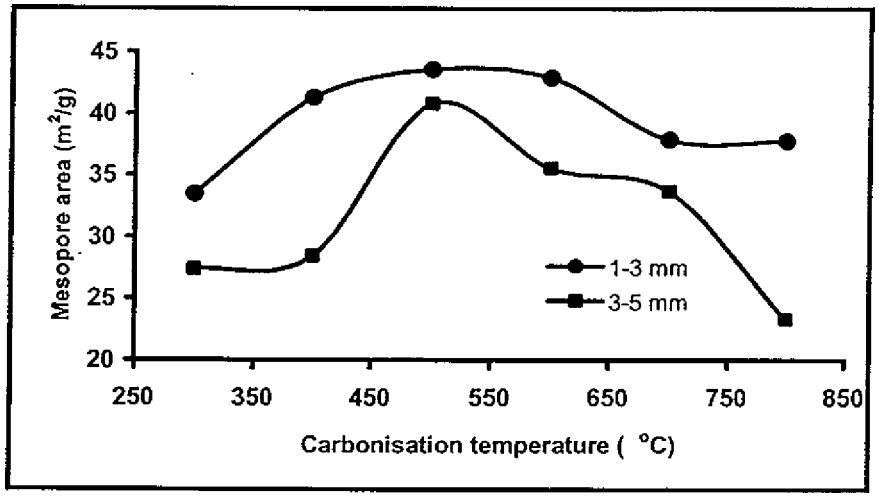


Figure 6 Mesopore specific surface area versus carbonisation temperature.

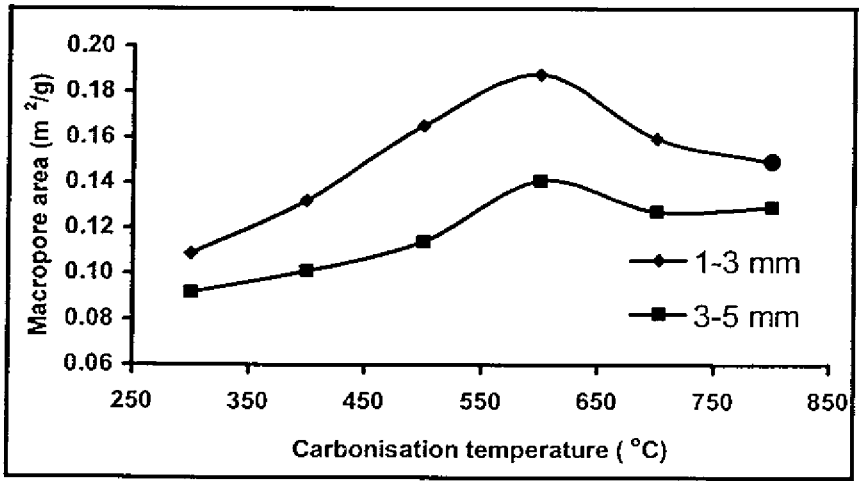


Figure 7 Macropore specific surface area versus carbonisation temperature.

Micropore volume

Figure 8 shows the micropore volume change with respect to the carbonisation temperature of the batch system. The results show a substantial micropore growth at temperatures between 300 to 400°C and moderate growth between temperatures of 400 to 800°C for both char sizes. According to Christner et al. (1993) the porosity increase started as early as during the degradation process, which is in the temperature range of 230 to 300°C. The micropores substantial growth might be due to the activation process with oxygen which occurred immediately after the formation of the pores as air was supplied continuously during the carbonisation process.

However, the continuous growth of micropore volume from 300 to 800°C does not agree with the findings by Wan Daud (1996), Christner et al. (1993), Mirasol et al. (1993) and Ternashi et al. (1969) as well as the reports of the coal-based chars by Chechowski et al. (1979), Toda et al. (1970) and Razouk et al. (1968) where they found that the micropore volume decreased after a temperature of 700°C. They assumed that in the region of 500 to 700°C, the material was undergoing aromatisation process, so that it was likely that the increase in the micropore volume was a result of rearrangement of the carbon units. The decreasing of the micropore volume above 700°C could be as a result of continuous rearrangement of the carbon layers which is sometimes termed graphitisation, whereby the carbon crystallites change from a highly disordered structure to a more orderly structure. The graphitisation causes the pores to become narrower or constricted. Wan Daud (1996) measured char density to investigate the phenomenon of pore narrowing with respect to the carbonisation temperature. His results showed that as the temperature increased the char density increased reaching a maximum at approximately 700°C. The initial increase was assumed to be caused by the reorientation of the carbon layers and the decrease of the char density was due to the transformation of open or accessible micropores to closed or inaccessible micropores.

Nevertheless, the findings by Satya Sai et al. (1997) where coconut shell was carbonised and activated with steam and CO_2 simultaneously showed a continuous growth of micropore structure, in fact, higher than that of coconut char which had undergone the same process. Again, the carbonisation procedure could cause a significant effect on the characteristic of the char produced. It seems that the presence of an activating agent at high temperature during the carbonisation process was more dominant than the aromatisation process. In other words, the continuous activation process could "preserve" the micropore structure and develop microporosity by creating new pores, opening closed micropores or by the breakdown of the wall of the micropore structure. However, an interesting part is whether the closed pores were opened or made accessible by the activating agent or were prevented from closing by the activation process during the aromatisation stage. Unfortunately, this phenomenon and the effect of pore shrinkage could not be resolved in this investigation. The higher micropore volume of the small size char could be related to the high reactivity.

Mesopore volume

Figure 9 shows the change of mesopore volume with respect to the carbonisation temperature of the char. The results show that the mesopore volume for both sizes of chars increased with increasing in the carbonisation temperature,

reaching a maximum at a temperature of about 500°C. However, the mesopore volume for the char range of 3 to 5 mm is lower than that in the size range of 1 to 3 mm. The decrease could be due to the shrinkage effect when the carbon structure becomes more ordered as the carbonisation temperature is increased.

Macropore volume

Figure 10 shows the change of macropore volume with respect to the carbonisation temperature of the char. The results show that macropore volume increases with increasing in the carbonisation temperature and reaching a maximum at 600°C. This is in accordance to the aromatisation process which occurs at temperatures of 500 to 700°C as obtained by many researchers (Wan Daud, 1996; Christner et al., 1993; Mirasol et al., 1993; Ternashi et al., 1969) as well as that of the coal-based char by Chechowski et al. (1979), Toda et al. (1970), and Razouk et al. (1968). It seems that the shrinkage process which occurred at high temperature had a significant effect on the macropore and mesopore volumes even though the air activation at the same time would probably enlarge the pore diameter.

Effects of activation temperature on properties of activated carbon

Surface area

Figures 11 shows the change in the specific surface areas of activated carbons at activation temperatures of 800°C and 900°C for the 1 - 3 mm and 3 - 5 mm size ranges, respectively, of the char produced. In general, the surface areas increased with increasing in the activation and carbonisation temperatures of the chars. On the effect of carbonisation temperature, Wan Daud (1996) found that the activation rate was faster for low carbonisation temperature char as compared to the high carbonisation temperature char. A similar trend was found by Mackay et. al. (1982). There are several postulations to explain this phenomenon. According to Mackay et. al. (1982) the decrease in the activation rate for high temperature char was due to the prolonged exposure of the char to high temperature, which resulted in the constriction of the micropores. As a result, it reduced the diffusion of the activating agent into the particles, therefore, lowering the activation rate.

Micropore surface area

Figure 12 shows the change in the micropore surface area for the activated carbon size ranges of 1 - 3 mm and 3 - 5 mm activated at 800°C and 900 °C with respect to the chars produced at different temperatures and periods of carbonization, respectively. Micropore surface area increases with increasing activation temperature and carbonisation temperature of char. The results obtained are in agreement to the results obtained by many researchers (Satya Sai et. al., 1997, Wan Daud, 1996, Mackay et. al., 1982, Reinoso et. al., 1991and Tomkow et. al., 1977). The increase in micropore surface area is due to the development of micropore at high temperature and longer period of char carbonisation.

Mesopore and macropore surface areas

The results show that the mesopore surface area increased with increasing in the activation temperature, char carbonisation temperature and carbonisation

period, as shown by Figure 13. These results are in accordance to those obtained by Wan Daud (1996); Reinoso et al. (1992); Reinoso et al. (1991); Wigmans et al. (1989). Reinoso et al. (1991) compared the mesopore development of the products activated with steam and carbon dioxide and found that the mesopore development of the product activated with steam was almost two-fold as compared to the product activated with carbon dioxide. Thus, it is reasonable to say that most of the mesopores developed in the activated carbon produced in this research was due to carbon dioxide activation. It was also found that the activated carbons derived from the chars produced at high carbonisation temperature had high mesopore development. A similar reason could also be applied for the increasing of the mesopore volume, whereby it increased with increasing in the activation period.

As expected higher surface area of mesopore was obtained in smaller particles as shown by Figure 13. This is due to the faster reaction rate of the smaller particles, which have pores more accessible to the activating agent. Therefore, the widening process of the micropores is faster in smaller particles; besides, higher micropore volume available in smaller particles could enhance the process. In the case of macropore surface area, a contrast pattern was obtained as shown by Figure 14.

Micropore volume

The development of micropore volume is presented by Figure 15 for the 1 - 3 mm and 3 - 5 mm size ranges at activation temperatures of 800 and 900°C. The results showed that the micropore volume increased with increasing in the activation temperature. With regards to the carbonisation temperature, the micropore volume increased linearly with increasing in the carbonisation temperature. The micropore development could be significantly affected by the creation of new pores by selective activation, the micropore network developed by the coupling of wall breaking and the marginal widening of the existing pores. The opening of previous inaccessible pores as suggested by Reinoso et al. (1991), could be less significant in this research due to the technique of the carbonisation process being carried out as air was used as the media during carbonisation as discussed earlier.

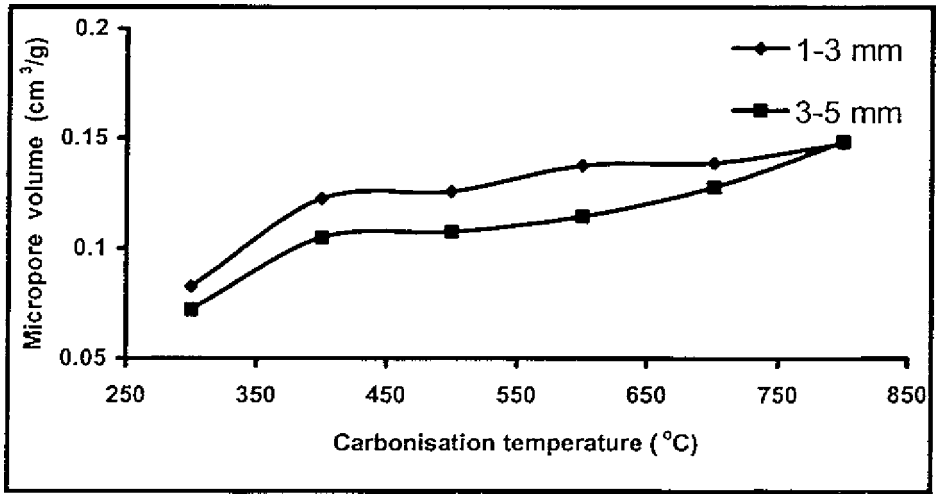


Figure 8: Micropore volume versus carbonisation temperature.

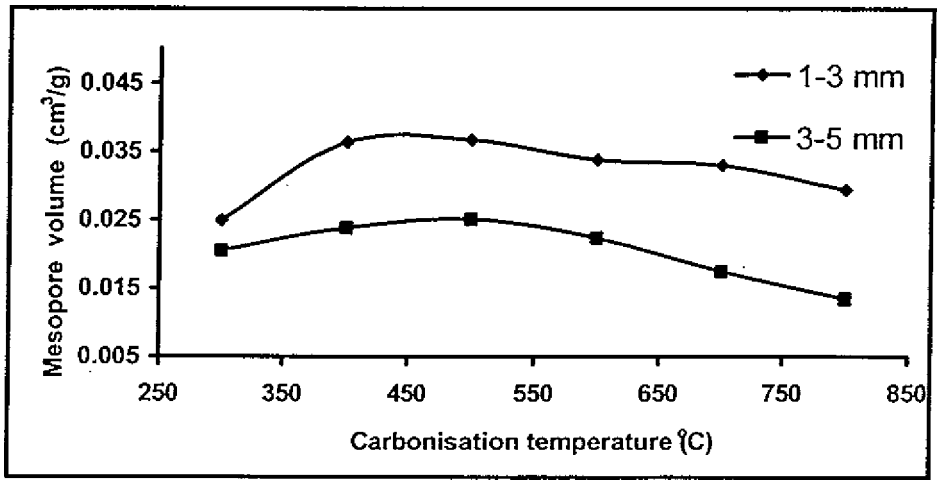


Figure 9: Mesopore volume versus carbonisation temperature.

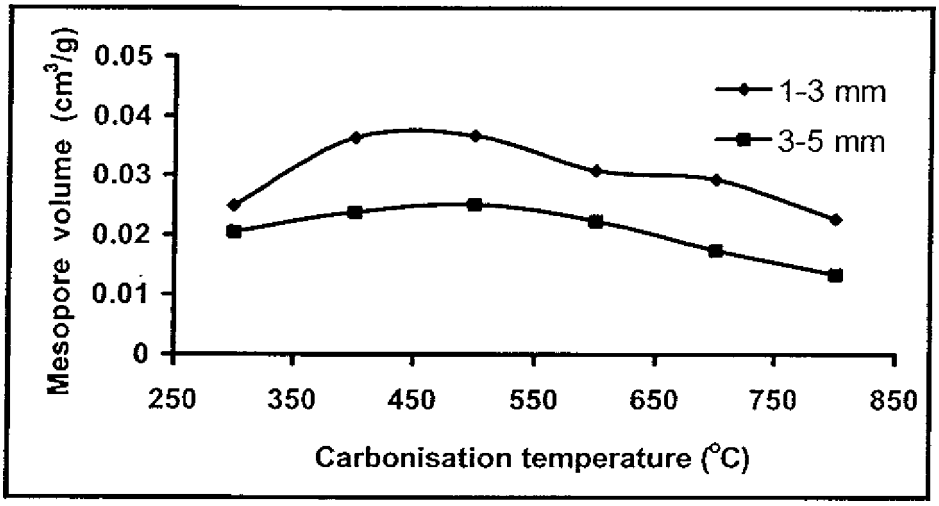


Figure 10: Macropore volume versus carbonisation temperature.

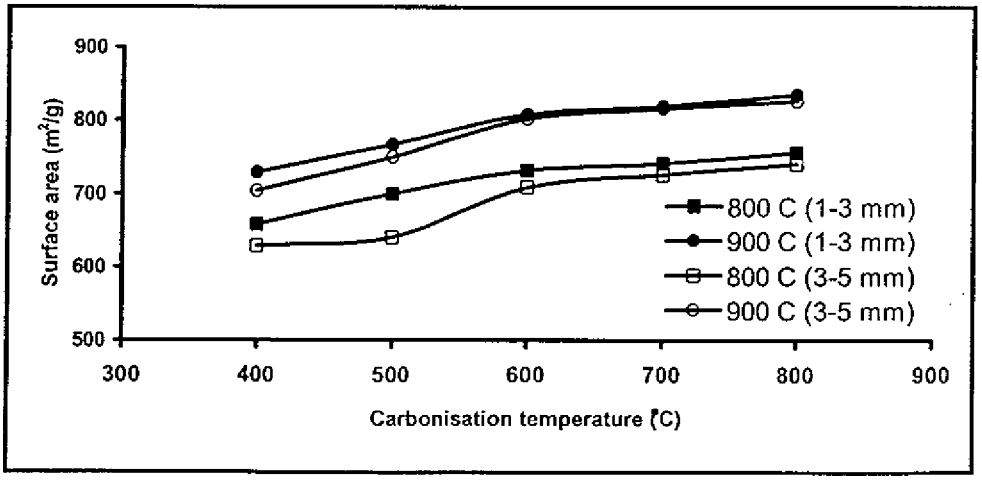


Figure 11: Surface area of activated carbon versus carbonisation temperature for two different size ranges.

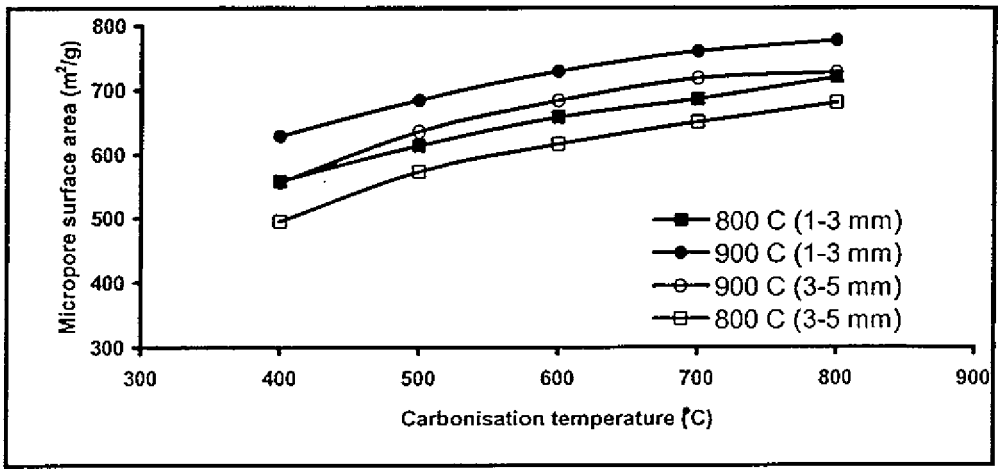


Figure 12: Micropore surface area versus carbonisation temperature for two different size ranges.

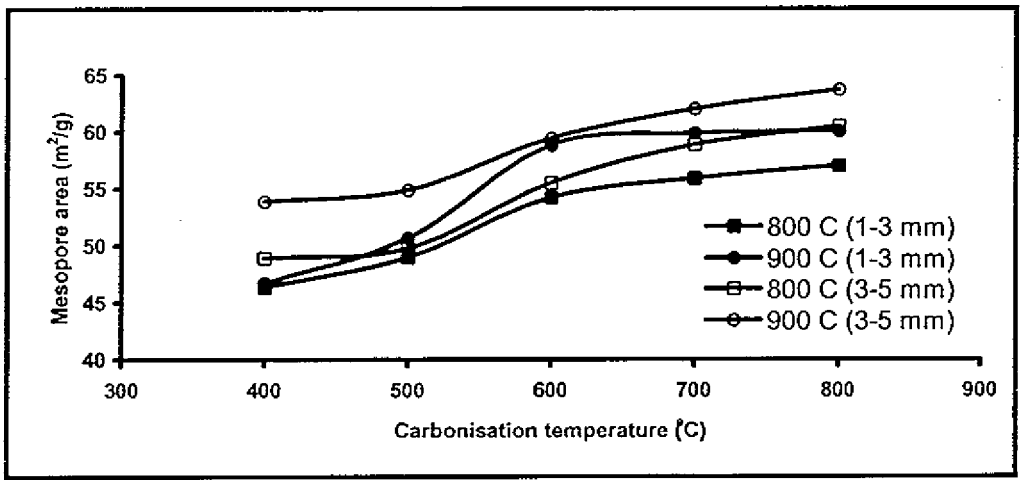


Figure 13: Mesopore surface area versus carbonisation for two different size ranges.

The results obtained by Satya Sai et al. (1997) for direct activation of coconut shell could be a good example for the above argument. However, several workers found contradicted results (Wan Daud,1996; Reinoso et al., 1991; Mackay et al., 1982). The most plausible reason is the carbonisation techniques employed by these workers were different, while in the current work and the work by Satya Sai (1997), a mixture of air and CO_2 was used as the activating agent.

Mesopore and macropore volumes

Figure 16 depicts the change in the mesopore volumes with respect to the chars produced at different carbonization temperatures and times for the 1 - 3 mm and 3 - 5 mm size-range of carbon activated at 800 and 900°C. The changes in the macropore volume are depicted by Figure 17 for the 1 - 3 mm and 3 – 5 mm size carbon activated at 800 and 900°C. The results show that the mesopore volume increased with increasing in the activation temperature, char carbonisation temperature and carbonisation period. Wan Daud (1996) found

that there was no effect upon increasing the activation temperature from 800 to 900°C for activated carbon produced from oil palm shell. Similar result was found by Wigmans et al. (1989) in the temperature range of 860 to 940°C; but upon further increase in the activation temperature from 1000°C to 1040°C the absolute mesopore volume decreased. However, Reinoso et al. (1991) used carbon dioxide as the activating agent and found that increasing the activation temperature from 825 to 950°C increased the mesopore volume. Since in this research, the activating agent is a mixture of steam, carbon dioxide (from gas combustion) and air, a different effect on the mesopore volume development is reasonable. Reinoso et al. (1991) also showed that using activating agent such as carbon dioxide and a mixture of air to steam significantly increased the mesopore structure. Thus, the increase in the mesopore volume caused by the increase in the structure of the mesopore in the activated carbon produced in this research is acceptable.

CONCLUSIONS

From this work, there are several conclusions can be made. The yield of char decreased with increasing in the carbonisation temperature. However, increasing the carbonisation temperature would result in an increase in the specific surface area of the chars. Microporosity of the char produced is higher as compared to the char produced by the conventional method. Mesoporosity and macroporosity of chars increased with increasing in the carbonisation temperature, reaching a maximum at 500°C and 600°C, respectively. For the activated carbon, the porosity increased with an increase in the carbonisation temperature of the original char. This is due to the higher porosity of the char produced at high carbonisation temperature than that produced at low temperature. It was also observed that char produced at high carbonisation temperature produced activated carbon with high microporosity. Mesoporosity and macroporosity of the activated carbons were marginally increased with an increase in the activation temperature.

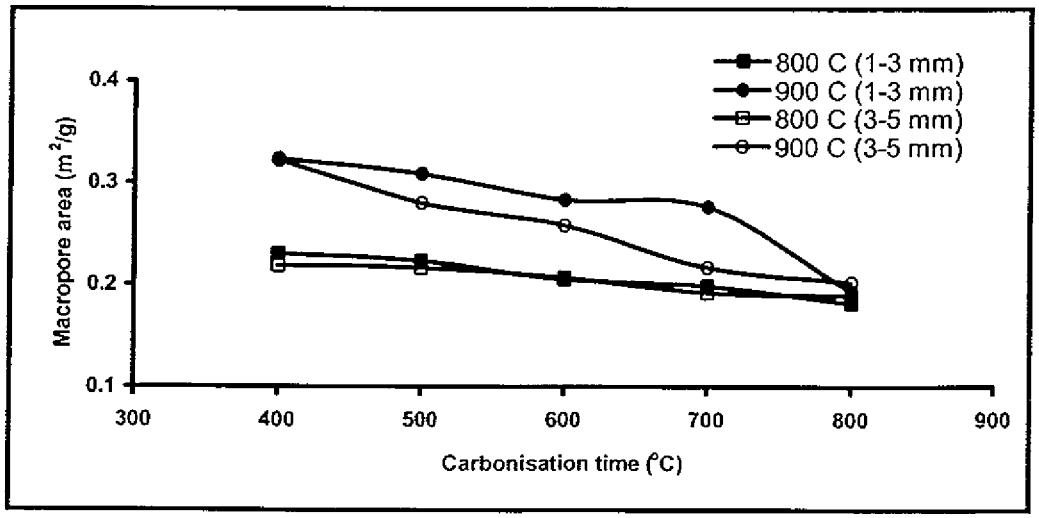


Figure 14: Macropore surface area versus carbonisation temperature for two different size ranges.

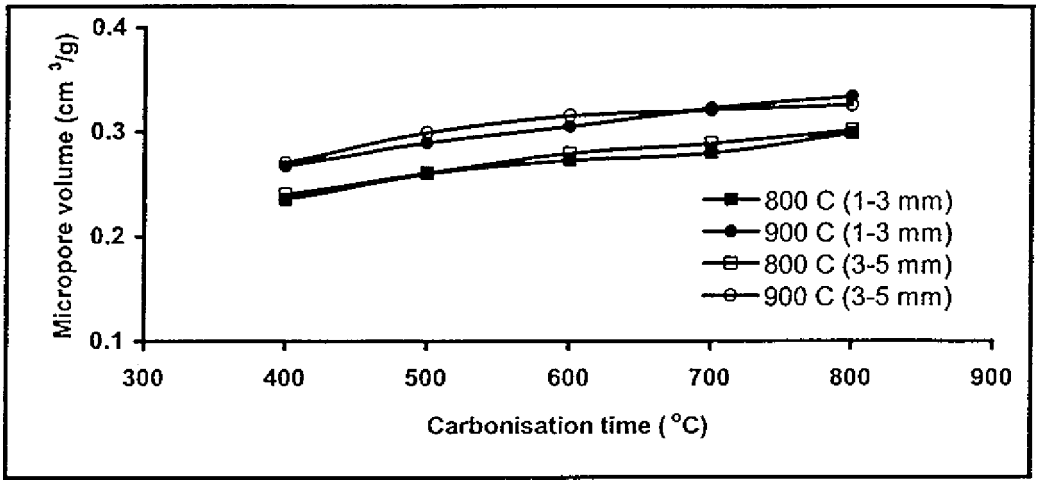


Figure 15: Micropore volume versus carbonisation temperature for two different size ranges.

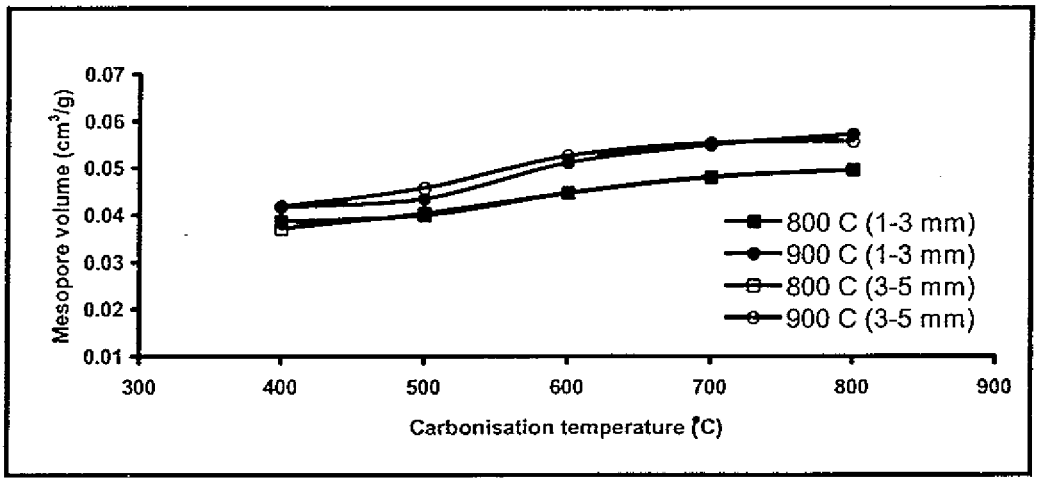


Figure 16: Specific mesopore volume of activated carbon versus carbonisation temperature for two different size ranges.

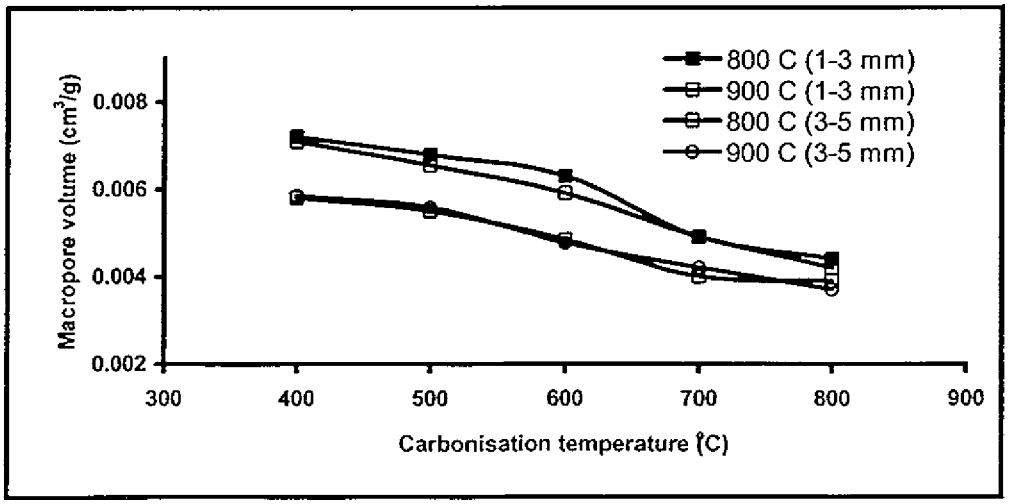


Figure 17: Macropore volume of activated carbon versus carbonisation temperature for two different size ranges.

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