야자곽 탄화로의 공정모델 개발

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Model Development of Carbonization Process of Coconut Shell

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1. Introduction

Carbonization has a long history of many millennia, because charcoal, its product, has been a favorite fuel for cooking. In the metallurgical industry a large amount of charcoal is used as the most useful reductant. The carbonization is a relatively simple process, high temperature treatment without air supply.

Charcoal from coconut shell is widely used in the production of activated carbon, and lots of VOCs are wasted during the charcoal production. Because most of the carbonization processes are small and the coconut shell is heavy for its transportation, the coconut shell is simply carbonized in an empty, half-open drum. Though the wasted amount of VOCs from the raw coconut shell is ranging from 62.5 % to 74.4 % according to the carbonization temperature, the VOCs have not been recovered until recently [1]. Many attempts have been made to recover the VOCs and to use them in the processes consuming lots of energy, such as steam boilers and power generation plants.

The activation of the coconut charcoal is yielded in the reductive gas environment, and the reductive gas environment is formed when the water gas reaction occurs to generate hydrogen. Though the reaction temperature is between 850 ℃ and 1100 ℃, the carbonization occurs at much lower temperature [2]. Unlike most of chemical processes handling liquid or gas, the production of the activated carbon involves solid material processing.

In this study, the process model of carbonization of coconut shell utilizing a rotary kiln is developed, and the role of parameters in the heat transfer at the kiln is examined to show the difference between the process models of carbonization and activation. The parameters include the convective heat transfer coefficients of wall to solid and wall to gas heat transfers. The optimal operating conditions of the rotary kiln are searched for the design and control of the kiln. In addition, the production and handling of the VOCs are explained as well.

2. Description of Carbonization Kiln

The rotary kiln is a cylindrical tube having screw-type fins attached outside of it for the enhanced heat transfer as demonstrated in Figure 1. The cylinder rotates, and is slightly inclined for the mixing and movement forward of the processing material. The structural difference between the carbonization kiln and the activation kiln comes from the heating system. While the activation kiln utilizes an internal heating and the insulation inside kiln wall, the carbonization kiln does an external heating. Therefore a brick chamber is necessary for the insulation as shown in Figure 1. The carbonization process is an operation of relatively low temperature, and the air supply is limited to prevent the burning of processing material. For the simulation of the kiln the process data from a pilot kiln is utilized here. The dimension of the kiln and the operating data of pilot test are shown in Table 1. The values listed in Table 1 and the schematic in Figure 1 were adopted from a pilot rotary kiln. Two pieces of rollers are placed each location for stable support. The product, charcoal, is evacuated from the rear end of the rotary kiln. When the hot charcoal contacts directly air, an explosion occurs. Therefore, a large chamber of excessive space is equipped at the rear section of the rotary kiln for the cooling of the charcoal. However, the chamber was not considered in the modeling of this study. The VOCs produced from the raw material are evacuated from the rear of the rotary kiln with the processed charcoal. When a large chamber is installed for the charcoal cooling, the chamber temperature has to be controlled to prevent the liquefaction of the VOCs. The VOCs in vapor phase is easier to transport, and the heat recovery is more efficient due to its high temperature. While typical flow rates of liquid are between 0.15 m/s and 0.3 m/s, those of gas are between 9 m/s and 30 m/s [3]. The practical moisture content in raw coconut shell is 10 %, but the moisture content is eliminated for the simple calculation and matching with the TGA data shown in Figure 2.

3. Results and discussion

The composition of volatile organic compounds (VOCs) in the coconut shell charcoal is not important, when it is only used for the raw material of the activated carbon production. However, in case that the VOC recovery is accompanied with the carbonization for an energy source, the VOC composition in the charcoal has to be minimized for the full VOC recovery. The processing temperature of the coconut shell determines the composition of the remaining VOCs in the coconut charcoal. The thermal gravimetric analysis (TGA) gives the information of the VOC content in the charcoal. Figure 2 shows the result of the TGA of the dry coconut shell. There are three different regions: the first is up to 330 ℃, the next is between 330 ℃ and 690 ℃ and the last is over 690 ℃. In the first region the vaporization of the VOCs is very fast as seen in the figure. The sudden drop of weight indicates the fast vaporization of the VOCs. In the second the drop is slow and steady. Though more recovery of the VOC is desirable, raising too much the processing temperature for the recovery of the VOC in the second region is not economical decision. In this study the cut-off temperature was set at a temperature of 500 ℃ after considering the economics of the temperature increase and VOC recovery. In the third region of over 690 ℃ burning occurs, and therefore there is a sudden weight loss and the final weight becomes zero.

The temperatures of solid and gas are calculated along the rotary kiln length, and they are plotted in Figure 3. The measured gas temperature at the middle of the pilot kiln was 430 ℃, and it was comparable to the calculated temperature in Figure 3. The calculated gas temperature at the middle of the kiln is 451 ℃, which is close to the measured temperature.

In other experiment, the measured gas temperatures in a rotary kiln were between 385 ℃ and 500 ℃ [4]. The measured temperatures are comparable to the computed temperature indicated in Figure 3. The effect of kiln wall temperature on the solid and gas temperatures is shown in Figure 4. The relation between the kiln temperature and the material temperature is almost linear. The plotted temperatures are the maximum over the whole kiln length for the given wall temperature. The solid and gas temperatures are simply displayed with the kiln outside temperature.

The model parameters presented in this study is adjusted with the data obtained from the pilot test carried out at a local company producing the activated carbon using the coconut charcoal. The energy source of the activation process is currently bunker-C oil, and therefore the reduction of the energy cost has been pursued. One of the options is utilizing the VOCs from the carbonization process, which is also necessary process for the raw material preparation in the charcoal activation plant. It is the reason that the recovery of the VOCs is important in the production of the activated carbon.

4. Conclusion

The model of the VOCs recovery process from coconut shell is proposed and simulated for the understanding of the process, which provides the basic knowledge of the kiln design and operation. From the simulation results, it is found that the convection from the kiln wall to the solid and gas is the dominant heat transfer in the kiln, and the convective heat-transfer coefficient between the kiln wall and solid has the most significant role in the control of solid temperature determining product quality. The analysis of the model parameters indicates that the kiln wall temperature and solid and gas temperatures are almost linearly dependent. When the external wall of the rotary kiln is heated at a temperature of 550 ℃, some 65 % of the raw coconut shell is recovered as the VOCs. For the refinement of the proposed model, more experiments have to be conducted and the operation and control of the kiln need to be investigated in the future.

References

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Table 1. Equipment characteristics and operating conditions

Length (m)	**1.2**	**Rotary kiln pressure**	**Atmospheric**
Internal diameter (m)	**0.2**	**Rotation speed (rpm)**	**4**
Raw material	**Coconut shell**	**Residence time (h)**	**1**
Solid flow rate (kg h^{-1})	**12**	**Solid input temperature (℃)**	**Room temperature**
Moisture content (%)	**0**	**Solid output temperature (℃)**	**200**
Yield (%)	**33**	**Inlet gas temperature (℃)**	**Room temperature**
Inclination	**5/1000**	**Outlet gas temperature (℃)**	**310**
Insulation thickness (m)	**0.05**		

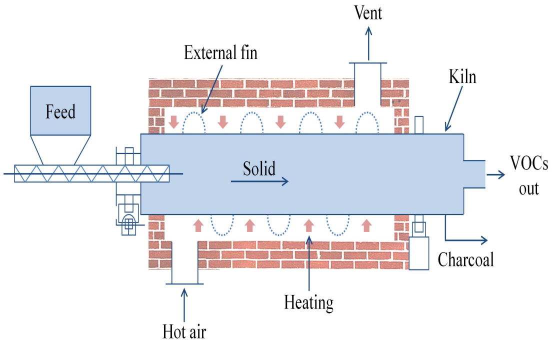

Figure 1. A schematic diagram of the rotary kiln for the carbonization of coconut shell.

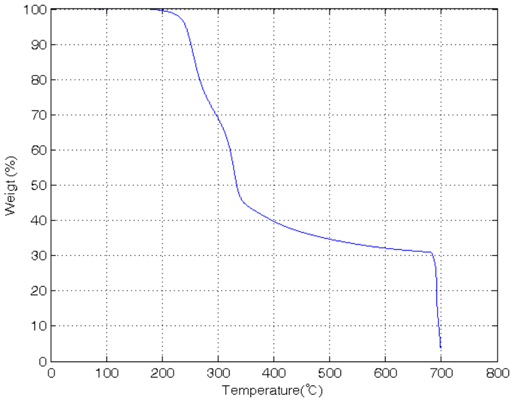

Figure 2. Weight variation with temperature increase in the thermal gravimetric analysis of dry coconut shell.

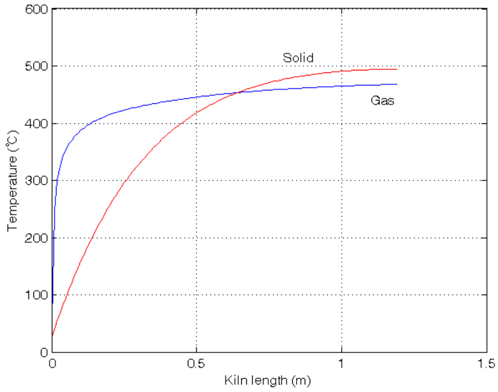

Figure 3. Temperature distribution of solid material and gas in the rotary kiln for the carbonization of coconut shell.

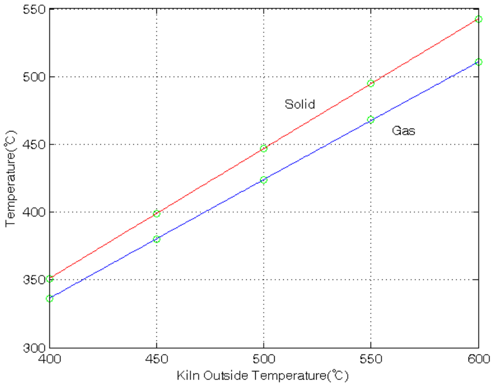

Figure 4. Effects of different kiln wall temperatures on solid and gas temperatures.