

# CHAPTER IX

## CONCLUDING REMARKS AND RECOMMENDATIONS FOR FUTURE RESEARCH

### 9.1 Introduction

In this chapter, the conclusions of the present work are drawn in section 9.2. Subsequently, the recommendations for future work are suggested in section 9.3.

### 9.2 Concluding remarks of the research

Much utilization of carbon microspheres with spherical shape is considerably attention from both scientist and industrial fields, in many aspects of template applications, catalyst supports, and Lithium-ion anode batteries. For the carbohydrate raw materials, the native starch is appropriate and well developed. For the hydrothermal process, the same reaction pathway can be observed in the different raw materials only if the hydrolysis reaction of the carbohydrates is slowly than the hydrothermal of glucose was directly dehydrated to yield intermediates. Therefore, hydrothermal process becomes one of the novel and promising methods to produce carbon microspheres. Furthermore, the carbonization process promotes the porous structure and crystallinity of the porous CMS particles.

The present study therefore devotes to thoroughly investigate the carbon microsphere formation mechanisms for a better understanding in this hydrothermal process. It was the first time that the decomposition behavior of native starch in the hydrothermal process was revealed and that the pseudo first order kinetic model of the decomposition of glucose (the native starch model compound) to describe the carbon microsphere formation was formulated based on the yield of the main liquid products.

Native corn starch is non-soluble starch which appears to be quite resisted to the decomposition and to subsequently form carbon microsphere at low reaction temperature. In the experiments using the native corn starch, native corn starch showed no decomposition up to 180°C (no carbon microsphere formation at 140°C)

and the carbon microsphere formation needed higher reaction temperature and reaction time around 3h. In the experiment, even if 5-HMF was produced at the relatively low yield, its further decomposition and polymerization were very large. In fact, with increasing reaction time, the 5-HMF yield decreased rapidly to form carbon microspheres. Morphology and particle size distribution of carbon microsphere strongly depended on reaction temperature and reaction time. The carbon microsphere particles gradually developed when the reaction increased at 180°C. The long reaction time needed to produce uniform particle size of carbon microsphere. Nonetheless, carbon microsphere particles seemed to sinter when the reaction temperature increased up to 220°C. The solid bridge formed between two particles which linked them together. This behavior was confirmed by TEM results. On the other hand, carbon microsphere particles from hydrothermal process of glucose have the smallest in size.

### **9.3 Recommendations for future research**

The present work is the early step of revealing the formation mechanism underlying the hydrothermal process. Therefore, there are still a number of possible directions to extend, improve it. The followings are the recommendations for future work:

- 1) The present work pays more attention to the reaction in the hydrothermal process where a lot of carbon microspheres are expected to form by neglecting mass transfer effects. Clearly, carbon microsphere particles at 220°C seemed to sinter each other which came from poor mass transfer of intermediates to grow carbon microsphere particles. This can be solved by designing the new process with well mixing impeller.
- 2) The carbon microsphere particles have reactive functional groups on their surface confirmed by the FT-IR results. However, this particularly property is suitable to immobilize metal ion species on the surface for constructing hollow oxide structure. To confirm this concept, the carbon microsphere particles will actually use to construct hollow oxide.

- 3) Carbon microspheres from hydrothermal process of native starch have larger in size than from hydrothermal process of glucose. The formation mechanisms need further explanation.
- 4) After carbonization process, the porous carbon microspheres have high development of surface area. This high surface area structure can be used as adsorbent materials. This application still needs to deeply investigate and further study. [76]