Research on Application of Nano Catalyst in New Electrochemical Energy Conversion

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Abstract

With increasing world energy consumption and demand, conversing compounds in wastes into reusable energy by new electrochemical energy conversion means has become major trend of current energy utilization and development. However, new electrochemical energy conversion in China is still in initial development stage and energy recycling efficiency is still lower nowadays. To effectively improve the energy conversion efficiency of compounds in wastes, this paper explored specific application of nano catalyst in new electrochemical energy conversion on basis of analysis of classification and common preparation methods of nano catalyst. The results show that nano catalyst has outstanding performance of electrochemical energy conversion and applying it in bioelectrochemical energy field, fuel cell and lithium ion battery can accelerate electron transfer and improve the energy conversion efficiency. This research provides important reference and guiding significance for promotion of new electrochemical energy conversion efficiency.

Keywords: Nano Catalyst, Nano Particle, Electrochemical Reaction, Energy Conversion, Application Research.

1. RESEARCH BACKGROUND

1.1 Literature review

Through the ages, human activities produced a lot of exhaust gas, solid waste and wastewater and useful compound resources in these wastes can’t be used effectively limited by utilization methods, so chemical conversion of wastes for efficient utilization of energy has become an important research topic of scholars (Dai et al., 2012). This paper discussed four methods of conversion of biomass energy into synthetic levulinate as well as the characteristics and future development trend of these methods in the aspects of reaction synthesis process, catalysis technology and economic feasibility (Kama, 2015). Some scholars carried out thorough research on methanol catalytic reaction successively and divided reaction into three types, namely, methanol to olefin, methanol to aromatics and methanol to gasoline, according to various catalysate (Kamat, 2011). This literature proved feasibility of three reaction methods through chemical experiment. Catalyst efficiency directly affects good conversion performance during the process of further conversion of renewable energy. Therefore, scholars have carried out some research on catalyst reaction, for example, scholars in energy academic circle carried out catalytic conversion of lignocellulosic biomass into widely used platform compounds (Peng et al., 2012). In addition, CO₂ recovery and utilization are an urgent task of controlling global warming. Under ambient conditions, CO₂ can be reduced to high value-added fuel and fine chemicals by electro-catalysis that has a wide application prospect (Liu and Liu, 2013)

In general, scholars at home and abroad have carried out sufficient research on waste conversion methods but still less discussion on catalyst efficiency, mainly concentrating on traditional catalysts. However in recent years, people discovered the nano catalytic effect, making nano materials show excellent performance in oxygen reduction, alcohol acid decomposition and other catalytic reactions. Therefore, this paper, based on the application of graphene and its nano-composites in bioelectrochemistry field, prepared efficient catalysts to provide theoretical basis and technical support for practical application.

1.2 Research purpose

Because of limited fossil energy reserves on earth and sustainable growth of human’s energy demand, development of new energy or energy recycling have been an important direction of current energy industry
development. Generally, there are two new electrochemistry conversion methods, that is, bioelectrochemistry system and ERR electrochemical reaction (co2-ERR). Mainly because two reaction methods have the potential to convert wastes into available energy and can be adopted when most scholars analyze energy conversion reaction (Yuan et al., 2016). However, low catalyst efficiency has become the bottleneck in conversion quantity and quality during waste conversion process and how to design and compound good catalysts becomes common issue in electrochemical conversion reaction of wastes. To this end, this paper analyzed the application of graphene nano-catalyst material in new electrochemical energy conversion as the core of application effect of nano catalyst in new electrochemical energy conversion, hoping to improve the electrochemical energy conversion efficiency with such catalyst and provide practical guidelines for disposal of enormous amount of waste produced in future social and economic development.

2. MAIN TYPES AND PREPARATION METHODS OF CATALYSIS

2.1 Main types of nano catalyst

Nano catalyst has advantages of deciding reaction path, reducing reaction temperature and improving reaction speed and efficiency. Nano catalyst can be divided into four types, i.e., metal nano particle catalyst, metal nano particle catalyst with substrate, semiconductor nano particle photocatalyst and nano-metal and semiconductor particle thermal catalyst, according to particle type, as shown in Table 1.

<table>
<thead>
<tr>
<th>Main type</th>
<th>Characteristics</th>
<th>Range of application</th>
<th>Application example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal nano particle catalyst</td>
<td>High activity and good selectivity</td>
<td>Hydrogenation of high polymer</td>
<td>Adhesive, sealant, catalyst or catalyst system, etc.</td>
</tr>
<tr>
<td>Metal nano particle catalyst with substrate</td>
<td>Extremely high activity and good catalysis</td>
<td>Wide range</td>
<td>Industrial production of catalysts</td>
</tr>
<tr>
<td>Semiconductor nano particle photocatalyst</td>
<td>Strong photoactivity, high photocatalytic efficiency and inexpensive</td>
<td>Wastewater treatment, organic matter degradation, failure pesticide degradation, etc.</td>
<td>Photo degradation of bisphenol, salicylic acid, and organic matters with benzene ring</td>
</tr>
<tr>
<td>Nano-metal and semiconductor particle thermal catalyst</td>
<td>Quite active</td>
<td>Fuel combustion-supporting and detonation</td>
<td>Explosive, rocket booster, coal accelerant, etc.</td>
</tr>
</tbody>
</table>

2.2 Preparation methods of nano catalyst

Preparation principle of nano catalyst is fixed at present, mainly including easy collection, high particle yield, controlled particle size distribution, etc. On basis of above preparation principle, common preparation methods include the following five types:

Firstly, hydrolysis method, that is, conduct the pyrolysis of metallic salt solution, then conduct double heating of hydrated oxygen and hydroxide precipitate to make it disintegrate to get catalysts. It mainly includes inorganic, spray and metal alkoxide hydrolysis and so on according to water types (Sun et al., 2010). Metal alkoxide hydrolysis method is the most common method thanks to simple preparation process, accuracy control of chemical composition of compounds, good powder repeatability and high production yield. But high material cost of hydrolysis method limits its application.

Secondly, precipitation method, namely, precipitate effective constituents in wastes through chemical reaction and then screen, dry, conduct pyrolysis and other operations of these effective constituents to get catalysts and operation is convenient. It includes coprecipitation, direct precipitation, coordinated precipitation and homogeneous precipitation methods according to precipitation ways.

Thirdly, solvothermal synthesis method, namely, make synthesis of oxide in fluid such as aqueous solution or...
steam by increasing temperature and pressure and then get nano catalyst by isolation or heating and other measures. This method has low environmental requirement and low cost, can control nano particle crystal type and has advantages of easily disperse compound, high nano particle purity and so on.

Fourthly, micro-emulsion method, namely, mix two solvents under the action of surfactant to form homogeneous emulsion, make low-dose solvent surrounded by high-dose solvent to form countless microvesicles (see Figure 1), and get catalysts by reaction in microvesicles (Yin et al., 2013). In this method, microvesicle surface is constituted by active agents and a series of chemical reactions such as nucleation, growth, coagulation and convergence are completed in spherical droplet (spherical particle) inside the microvesicle, effectively improving catalytic efficiency. This method has a good prospect because of simple and handy experimental facilities, small diameter of nano particle and good monodispersion.

![Figure 1. Microvesicles Constituted by Surfactants](image)

Fifthly, sol-gel method, namely, get homogeneous metal non-oxide or oxide sol through aggregation or hydrolysis of metal alkoxide, and concentrate it to clear gel and heat the gel to get catalysts through horizontal distribution of groups of molecules. Although this method needs a long treatment time and relatively expensive raw material and uses poisonous organic solvent, it is widely applied because of small diameter of nano particles gotten, low sintering temperature, high uniformity and pureness as well as easily controlled reaction process.

3. APPLICATION OF NANO CATALYST IN NEW ELECTROCHEMICAL ENERGY CONVERSION

Nanometer catalyst is called “fourth generation catalyst” and has been well-known by science researchers now. Selection and catalytic performance of nano catalyst is superior to traditional catalyst because of obvious surface feature of nano particle and specific crystal structure, so it is an important research important of catalyst for waste energy (Mao et al., 2012). Here is a typical case, the researcher prepared easily fluidizing methanation nano catalyst with catalytic activity by catalyst structure modeling and such catalyst can be directly applied to fluidized bed reaction and provides suitable conversion scheme of fluidized bed methane chemical process.

3.1 Application of nano catalyst in bioelectrochemical energy field

Nano catalyst can promote the bioelectrochemical energy conversion effect and strengthen the bio-energy recycle effect. Graphene with larger surface area is an ideal carrier of fixation of biomolecule. Under existing experiment conditions, firstly, prepare graphene compound with catalytic and conversion functions (namely, nano catalyst) and this compound has good electro-catalysis of oxygen and hydrogen peroxide. Specific reaction is as shown below

\[ \text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O} \quad E_e = 1.2648\text{V} \]

Then, fix superficial glucose oxidase on graphene surface designedly with ionic liquid, PVP and other substances to generate a glucose biosensor, used to check whether glucose oxidase shows direct electron transitivity and maintains biological activity. Monitoring range is 3-15mol now and the reaction is as shown below:

\[ 2\text{H}_2 \rightarrow 4\text{H}^+ + 4\text{e}^- \quad E_a = 0.000\text{V} \]

At last, conduct genetic surveillance of specific fragment with DNA electrochemical sensor to realize simple,
precise and micro disease diagnosis. Many types of fuel cells have been built at present and they use the same principle. These nano catalysts consist of anode, cathode and electrolyte basically. For example, hydrogen is pumped to an electrode (anode), oxygen is broken down into electrons and protons, when protons diffuse into the other electrode (cathode), electrons flow from anode and generate electric energy, and then protons, electrons and oxygen combine and produce water. Electronic reaction equation is as shown below:

\[ 2H_2 + O_2 \rightarrow 2H_2O \quad E_{cell} = 1.2648V \]

Above experiments show that after removal of surface adhesive chemical substances and coupling agent, enzyme can be easily fixed on graphene surface and completely maintain biological activity and chemical conformation; the experiment of graphene oxide can fully transfer protein, indicating that nano catalyst can be applied in biosensing field.

### 3.2 Application of nano catalyst in fuel cell field

Fuel cell is a device directly conversing chemical energy into electric energy and has advantages of no pollution, high energy conversion efficiency, such fuel cell mainly produces oxidation reaction and cathode oxygen reduction (Zhang et al., 2013). So, selecting high-performance electrocatalyst is an important direction of using high energy of fuel cell. Particularly, physical properties and catalytic and conversion performance of catalyst carrier obviously affect the interaction with catalyst and thus affect catalytic performance. Graphene, as a new carbon material, can be applied in fuel cell field as the carrier of metal catalyst because of high special electron conduction ability. Reaction equation in catalytic performance is as follows:

\[ 2H_2O^+ + 2e^- \xrightleftharpoons[k_{-c}]{k_c} 2H_2O + H_2 \]

On basis of existing experiment, prepare the graphene-metal (Au, Pt, Pd) nano-composites with graphene oxide; take metal ion and graphene oxide as precursors and get graphene nano-composites by one-step reduction; reduce H_2PtCl_6 with sodium borohydride and get some reduced Go-Pt catalyst, conduct heat treatment of such Go-Pt catalyst at 300°C for 8h, and get the following equations through heat treatment:

\[ H_2O^+ + M + e^- \xrightleftharpoons[k_{-c}]{k_c} H_2O^0 + M^- + H \]

\[ 2M^- + H \xrightarrow[k_{r_t}]{k_t} 2M + H_2 \]

Prepared graphene-Pt nano-composites can be as direct anode catalyst of methanol fuel cell. Experimental results show that electrochemical active area (ECSA) of the catalyst is increased by 80% compared with that without any catalyst carrier, and graphene as electrocatalyst carrier can effectively improve the catalyst ECSA and then further enhance its electro-catalytic performance in fuel cell.

### 3.3 Application of nano catalyst to lithium ion battery

Energy conversion function of nano catalyst is also embodied in lithium ion battery. Under existing experimental conditions, firstly, make anionic surfactant act on graphene to produce certain chemical reaction to increase anions. Conduct further experiment, add active agent on anion surface to promote the growth of TiO_2 in graphene sheet to strengthen the stability of graphene sheet. Thus, in case of TiO_2 load on graphene surface, get nano catalyst through chemical reaction, and specific reaction equations are as follows:

\[ TiO_2(s) \xrightarrow{h^+} TiO_2(e^- / h^+) \]

\[ h^+ + H_2O \rightarrow OH^- + H^+ \]

\[ e^- + O_2 \rightarrow O_2^- \xrightarrow{h^+} HO_2^- \]
In this process, TiO$_2$ in lithium ion battery shows good performance because graphene participates in reactions and the capacity is more than that of ordinary pure TiO$_2$ electrode material at high charge and discharge rate. Secondly, get porous electrode material of lithium ion battery with graphene and SnO$_2$, causing the catalysis in lithium ion battery. Thirdly, use LiFePO$_4$ modified by graphene as cathode material of lithium ion battery; dry it further to form LiFePO$_4$/graphene compound. The experimental results show that the capacity of lithium ion battery can reach 810g after catalysis, greatly improving cycle performance of electrode material. So, applying nano catalyst to lithium ion battery can accelerate electron transfer, increase the gap between graphene and related element, and help Li$^+$ diffusion, showing outstanding electrochemical performance.

4. CONCLUSION

With rapid development of the national economy, energy demand of all sectors of society is increasing, while total traditional fossil energy is limited, so China is facing the uncoordinated energy supply and demand. Although our country has increased the development and construction of electrochemical energy conversion in recent years, the energy supply and demand contradiction still exist because of lower energy recycling efficiency, restricting the process of development of China energy field. To improve the energy conversion efficiency of compounds, this paper explored specific application of graphene nano catalyst as a representative in three new electrochemical energy conversion processes on basis of analysis of features, classification and preparation methods of nano catalyst. The research discovered that nano catalyst has outstanding performance of electrochemical energy conversion and applying it in bioelectrochemical energy field, fuel cell and lithium ion battery can accelerate electron transfer and enhance energy conversion efficiency. This paper researched the effect of electrochemical energy conversion from the perspective of advantages of nano catalyst and taking a specific nano catalyst in new electrochemical energy conversion as an example and recommended to carry out a deeper and more meticulous research in aspects of taking other nano catalysts in new electrochemical energy conversion as examples, conducting experiments on electrochemical conversion effects under different environmental conditions and efficient application methods of nano catalysts in new electrochemical energy conversion.

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