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Construction and Stability Studies on Industrial Chain Network of Circular Economy of Organic Chemical Industry

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In order to offer theoretical foundation and reference model for the development of circular economy of chemical industry in our country, this paper analyses the current status and issues in chemical industry with overseas study trends and practical application of circular economy. Based on the concept and theories of circular economy, this paper designs a series of circular economy target system of chemical industry, builds the effectiveness evaluation model through combining with practical situation of chemical industry, and proposes that building chemical industry parks is the reasonable model of circular economy development.

1. Introduction

The chemical industry is the important raw materials industry for national economic development and plays a very important role for the economic construction of our country. And meanwhile, chemical industry is also a typical traditional economic development model and a resource-intensive industry with high energy consumption and high-pollution, which is contrary to the purpose of social economy and environment sustainability development (Gołaszewska-Kaczan et al., 2015; Shujie et al., 2015). In the meantime, the chemical industry is also one of the most potential industries to develop the circular economy, how to change the single end pollution control and treatment mode (Zhou et al., 2017), reasonably utilize natural resources, achieve whole-process control of industrial pollution and realize sustainable development of chemical industry, and take a new road to industrialization (Michael and Amir, 2016; Donald et al., 2015), which is also a very important subject.

Under such circumstances, some developed European and American countries rearrange the industry development direction in order to improve composite economic results, avoid environmental pollution with the ecological idea, positively carry out “circular economy” (Jagdeep and Isabel, 2016)—— to convert the traditional economy of linear growth that relies on resource consumption to the economy relying on ecological resources to get development within the system of human (Shu et al., 2015), natural resources and science and technology (Alan et al., 2017; Geng et al., 2012; Hill, 2014). They propose to establish an economic development model on the basis of continuous circular use of materials, requires to organize economic activities to be the process of resources recycling flow of “resources-products-renewable resources” and “production-consumption-recovery processing-reproduction-consumptio” according to the mode of natural ecosystems (Junior et al., 2014; Schneider, 2015), reduce the production of wastes through sufficiently utilizing current resources, and fundamentally solve the conflicts between environment and economic development (Su et al., 2013).

2. Development status of circular economy of chemical industry

2.1 Circular economy and industry chain of circular economy

The circular economy is a new economic growth pattern, means to center on the efficient utilization and cyclic utilization of resources (Roger, 2016), recycle wastes during economic development process, and gain the maximum outputs and the minimum waste discharge by consuming as few of resources as possible and paying as little of environmental costs as possible based on 3R principles (Ming et al., 2016, Miria et al., 2016),

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i.e. Reduce, Reuse and Recycle, the basic characteristics of which are low consumption, low emission and high efficiency.

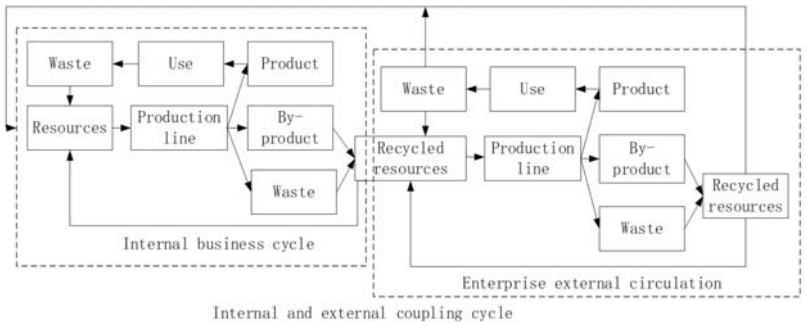

Figure 1: Diagram of circular economy of enterprise

The most important point of circular economy lies in the cyclic utilization of the by-products and wastes produced from every production chain (Lu et al., 2014; Qing et al., 2015), and forming the circular operation mode of "resources-products-by-product/wastes-renewable resources", which has three kinds of structural styles, i.e. internal recycling, external recycling and coupling mode, as shown in Figure 1.

The industry chain of circular economy represents circular economy directly in industrial park (Nicola et al., 2017). The industrial chain is a complicated research field, referring to the relevant theories of industrial economics, technological economics, development economics, regional economics and management science and many other subjects, it requires to consider the influence of material supply, industrial relationship, additional value, full life circle of products, circular footprint and many other factors. It needs to observe the following principles in order to build the industrial chain of circular economy of chemical industrial parks:

□value increase principle, no matter the industry chain develops in the form of the vertical extension or transverse coupling, the value of products cannot be reduced, which is the basis that the industry chain can exist; □ clean principle, the enterprises on industry chain shall save raw materials and energy and reduce the amount or environmental toxicity of wastes as much as possible during production process; □ flexibility principle, it is not allowed to reduce the flexibility of the original industry chain to the unacceptable restricted level because of building the industry chain of circular industry, which shall be decided by the estimated risk specifically; □ operability principle, it needs to combine with industrial development orientation, sufficiently utilize wastes and by-products that can be used based on the current industry chain system, develop the potential among existing industry chains, and introduce supplementary chain and enterprises that can increase flexibility.

During the process of specific planning and construction, according to "3R" principles of circular economy, through combining with the practical situation of chemical industrial parks, the construction of industry chain can be divided into: □ the construction of main industry chain, which refers to mainly consider the mutual supply of materials, introduce supplementary chain and enterprises that can increase flexibility; □ construction of auxiliary circular chain, which refers to mainly consider water chain, energy chain, information chain and other public works and part of enterprises that can increase flexibility, as shown in Figure 2.

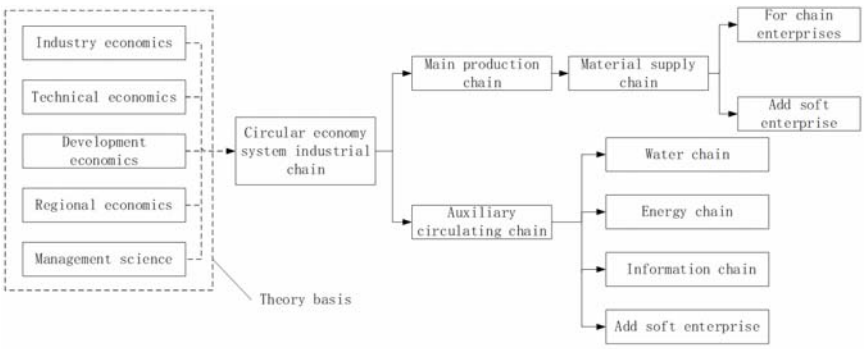

Figure 2: Construction of circular economy industrial chain

2.2 Development status of circular economy of foreign chemical industry

(1) Dupont—internal circular economy pattern of enterprise

The inner-enterprise circular economy pattern of Dupont is to extend production chain through organizing material circulation among each technological process, reduce the usage amount of materials and energy during production process, decrease the emission of waste and toxic substances as much as possible, and utilize the renewable resources to the utmost extent, Dupont is the first corporation in the world that takes "reducing wastes and emission to zero" as the goal of development, and also integrates the concept of "safety, health and environmental protection" into the activities of the enterprise.

At the end of 1980s, the researchers of Dupont used factory as the laboratory to test the theories of circular economy, innovatively developed 3R principles to be "3R manufacturing method" that combines with practical situations of chemical industry, in order to reach the environmental protection objective of less emission and even zero emission. By 1994, the plastic wastes generated during production had been reduced by 25%, and the emission amount of air pollutants had been reduced by 70%. And meanwhile, they recycled chemical substances from waste plastics, such as discarded milk box and disposable plastic container, and developed durable ethylene material "VICK" and other new products.

(2) Kalundborg in Denmark—inter-enterprise circular economy

Kalundborg industrial park in Denmark is the most typical representative of industrial ecological system in the world at present, such kind of operation mode can be named as inter-enterprise circular economy, the components of enterprise cooperation network is shown in the following diagram:

Table 1: Communication results for different communication distances

Company Name	Raw materials	Product	Waste
Gypsum factory	Gypsum	Gypsum board	
Microbial company	Sludge	Soil	
Power plant	Can be gas. Coal. Cooling water	Heat. Electricity	Gypsum. Fly ash. Thio
Refinery	Crude	Refined oil	Can be gas
Pharmaceutical factory	potato powder. Corn starch	Insulin and other drugs	Waste residue. Waste water. Yeast
Waste disposal company.	Waste residue. Waste water	Electricity. Can be gas	
City Hall	Water. Heat. Electricity		Gypsum. Sludge

The power station is located at the centre of this industrial ecological system, and utilizes thermal energy by different stages: provide thermal energy for about 5000 families in Kalundborg, reduce a large amount of dust emission; the power station provides process steam for oil refinery and pharmaceutical factories; compared to separate production, the fuel availability is increased by 30% through the combined heat and power generation. Part of cooling water of power station was delivered to fish farm, such fish farm owns the annual output of 200 ton of trout, and the trout is suitable for growing in the water of higher temperature. 200,000 ton of gypsum can be produced by the desulphurizing equipment of power station every year; the gypsum is sold to gypsum board factories, which reduces the consumption of natural gypsum and also decrease the amount of solid landfill. In addition, the by-product of desulfuration factory--ammonium thiosulfate, the waste water and waste residue generated by pharmaceutical factories and residual sludge from municipal wastewater treatment plant are also converted to resources and utilized in many other fields.

(3) "Garbage economy" of Germany—circular economy at social level

DSD in Germany is an intermediary organization specialized in collecting and disposing package waste, composed by manufacturers of products, packing materials manufacturers, commercial enterprises and garbage collection departments jointly; it organizes relevant enterprises to form a network according to the principle of voluntariness, and mark on the packages to be recycled, and DSD entrusted recycling enterprises for disposal. In Germany, the water charge of residents includes enough sewage treatment fee, the water charge for domestic use is 7.5 Mark/m³, in which 1/3 is paid to drinking water companies and 2/3 to waste water treatment companies. And waste water treatment companies allocate 1/3 of the fund received to sewage treatment plant and 2/3 to sewage transmission pipe network. At present, the recycling rate of many industrial wastes in German, such as waste metal, abandoned automobiles, scrap tire, waste glass and used oil, almost reaches 100%. After dozens of years of continuous efforts and practice, the circular economy in Germany has made obvious achievements, under the condition that GDP is increased over two times, main

pollutants are reduced by nearly 75%, and the “win-win” result of economic and environmental benefit is realized.

3. Development model of circular economy of chemical industry in our country

3.1 Establishment and stability analysis of industry chain network

The eco-industry park is a new-type organization form of the industry chain of circular economy, the logistics and energy flow of industrial parks are designed through the simulation of natural ecological system, the typical structure of industrial chains of chemical industrial parks has a upstream enterprise, which supplies raw materials for downstream enterprises, the supply chain of materials is shown as Figure 3.

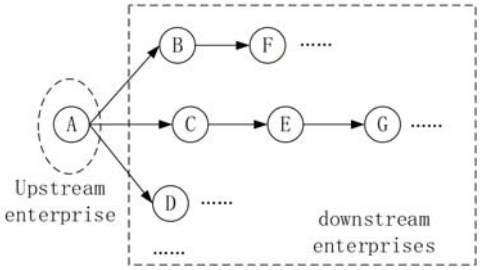

Figure 3: The schematic diagram of material supply chain of typical chemical industrial park

During the process of the stability analysis of industry chains, it may be found that certain enterprises have relatively large risk, and some enterprises that have larger risk also have larger contribution value for the overall risk of industrial chain, at the moment, it may be feasible to introduce the enterprises that can increase flexibility to reduce the risk of industrial chain, for example, the upstream enterprises have a large amount of propylene to supply to downstream enterprise A, but due to single product structure of enterprise A or its production equipment requiring frequent shutdown for overhaul, it causes large risk of enterprise A, at the moment, enterprise B that uses propylene as main raw material can be introduced in to reduce the risk of the industrial chain, and then enterprise B is the one that can increase flexibility, as shown in Figureure 4. Through comparison of the situations before and after increasing flexibility of industrial chain, the industrial risk of upstream enterprise in propylene is decreased greatly due to the introduction of enterprise B. As the core enterprise of industrial chain of the park, the risk of upstream enterprise will be delivered to the downstream of industrial chain along with the material supply chain, reducing the industrial risk of upstream enterprise will reduce the risk of overall industrial risk and increase the stability of industrial chain.

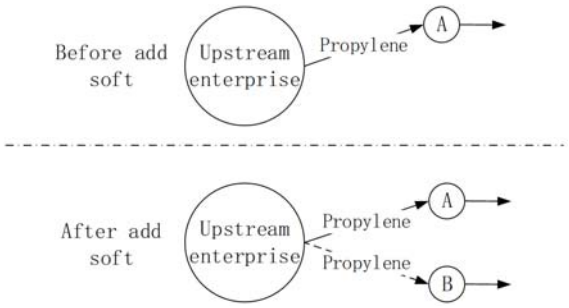

Figure 4: Industrial chain schematic before and after add soft

3.2 Design and evaluation of the target system of circular economy

According to connotation of circular economy and practical situation of chemical industry, the target system of circular economy is broken up into the following five essential indicators:

(1) Usage indicator of Resource reduction: the energy (material) consumption of gross output value of RMB 10,000 = [energy (material) consumption amount × unit price of raw material]/10000×100%;

(2) Emission indicator of pollution reduction: the disposal rate of wastes with gross output value of RMB 10,000 = [the processing capacity of wastes with gross output value of RMB 10,000/ total output×100%;

(3) Resource recycling and reuse: the multipurpose utilization rate of “the three wastes (waste gas, waste water and industrial residue)”= the output value of comprehensive utilization/ total industrial output value×100%;
(4) Economic benefit indicator: including total industrial output value (in the unit of RMB100,000,000) and average per capita income (RMB) and others;
(5) Development ability indicator of circular economy: science and technology investment rate= environmental protection technology investment/ total industrial output value×100%;
The effect evaluation indicator system for the development of the circular economy of the chemical industry in our country has the developing the circular economy, therefore, the evaluation on the effect of developing the circular economy of the chemical industry is also a process of layer-by-layer weighting and composite calculation. The mathematic model is: set the nth relative evaluation value of the m-th element A to be Vmn, the corresponding weight is αn, and the comprehensive evaluation value of element Y is:

$$Vm = \sum_{n=1}^{4} \alpha_n V_{mn} \tag{1}$$

After the comprehensive evaluation on all five elements is done, the weighted average of the comprehensive evaluation value is calculated, the weight is the proportion of such element βm, and then the comprehensive evaluation value V of developing the circular economy of chemical industry is:

$$V = \sum_{m=1}^{5} \beta_m V_m = \sum_{m=1}^{5} \sum_{n=1}^{4} \beta_m \alpha_n V_{mn} \tag{2}$$

The value range of V is 0-1; the five-stage classification is shown as follows:
0.9-1.0 the mature stage of circular economy
0.8-0.9 improvement stage of circular economy
0.7-0.8 development stage of circular economy
0.5-0.7 the stage converting from traditional economy to circular economy
0-0.5 traditional economy

4. Conclusion

The chemical industry occupies an important position in industrial production and national economy and plays an important role in social and economic development in China. At present, opportunities and challenges coexist in the chemical industry in our country; under such situation, realizing circular economy is the only route which must be passed in order to get further development of the chemical industry of our country. The meaning of circular economy development of chemical industry is to take full advantage of resources and energy, realize cleaner production, harmless and resourceful treatment of wastes, and build eco-industry parks that interact with the ecological chain of other industries, to supply resources and dispose pollutants for each other, and achieve resource regeneration and coordinative development. The circular economy of overseas chemical industry has made outstanding achievements, the circular economy of our country is also developing vigorously, and the energy conservation and environmental protection also has got remarkable achievements on a certain level. We will continue to focus on the technology closely related to sustainable development and various kinds of technology that develops by coordinating with other industries in resource and energy structure optimization.

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