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Overview of Smart Factory Studies in Petrochemical Industry

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Abstract

The smart factory in petrochemical industry is operational excellence as the goal, through the operational management of the whole process, with a high degree of automation, digitization, visualization, modeling and integrated refining chemical factory, which is the future development direction of the petrochemical enterprises. This paper discusses the development process of petrochemical industry smart factory, describes its architecture and key technologies. Then based on industry background, the paper gives a smart factory model definition. It puts forward thesis in production control, equipment management, HSE management, energy management, supply chain management and decision support six business domain as the focus, information technology and standardization to support the petrochemical smart factory "6+2" model framework. Finally, the paper points out the future development trend of smart factory and further research directions.

Keywords: process system engineering; petrochemical industry; smart factory

1. Introduction

The industry of petrochemical has become the large modern industrial system after decades of development, and it has made great contributions to the development of world economy and the improvement of people's lives. In recent years, the size of the petrochemical industry has been enlarged and industrial patterns have also changed considerably (Kadambur and Kotecha, 2015), which made regions play increasing role in the petrochemical industry, like North America, the Middle East and Asia-Pacific. The whole related industry has quickened the adjustment of the industrial structure, and began to transform from the stage of scale-economy to that of quality-effectiveness-economy. Product structure is reforming remarkably, and output of highly-performed, high value-added, specific chemical increase day by day (Industrie 4.0 Working Group, 2013). The development of petrochemical industry has been more and more limited by the resources and protection of environment. Driven by the Technology Revolution, the petrochemical industry will develop rapidly with the help of the technical innovation (Khosravi et al., 2015; Ramteke and Srinivasan, 2011). And the combination of new information technology, operation technology and manufacturing technology will bring great changes in the production patterns of petrochemical industry (Sa'idi et al., 2014).

In such background, traditional industry of petrochemical has not adapted to the requirement of the customer, market and the technology development. A new production pattern needs to adjust to the new changes of shorter product life cycle (Industrie 4.0

Working Group, 2013), to cope with the rapid upgrading of many types of products in small scales, to ameliorate the effectiveness resource optimization and energy utilization, to satisfy the need of global manufacturing and sustainable development of enterprises. Therefore, smart factory seems to be the best choice.

2. The emergence and development of smart factory

In recent years, Smart factory has been widely mentioned in the business and academic circles (Lucke et al., 2008; Radziwon et al., 2014). In some papers, Yoon et al.(2011) used Ubiquitous Factory (U-Factory), Zkule (2011) used Factory- of- Things (FoT) to explain the concept of smart factory. In addition, the key factor of Smart Process Manufacturing and German Industry 4.0 (Industrie 4.0 Working Group, 2013) is also smart factory.

2.1. Ubiquitous Factory

The PARC in Xerox put forward the concept of ubiquitous computing, which allows the small, low-cost, networked devices to distribute in various places in our lives (Weiser, 1991; Zuehlke, 2010). In the model of U-computing, people can acquire and process the desired information by any method, anytime, anywhere. As the development of sensor net, RFID etc., the U-Computing has many specific forms, such as U-home (Lai et al., 2013) etc.. Yoon (2012) came with up the concept of Ubiquitous Factory. He pointed out that the frame of the U-Factory should integrate the information technology, advanced manufacturing technology and automatically complete the whole industrial process through the data acquisition and exchange of workers, resources, products and systems. The frame mainly consists of four parts: U-human, U-Resources, U-Product, and U-MES.

2.2. Factory-of-Things

MIT founded the Auto-ID Center, and Ashton (2009) put forward the concept of the Internet-of-Things (IoT), which means that all items are connected through the RFID and the Internet, can realize the intelligent identification and management. The IoT requires that items automatically acquire and process data, exchange information with other items (Maass and Varshney, 2012). The IoT is more like an uncertain and open network, in which the intelligent devices and pseudo entities are endowed enough capacities to complete the required operation independently according to the goal and circumstance (Lucke, et al., 2008). Based on the IoT, Zuehlke (2010) held the opinion that the future factory should be the Factory-of-Things (FoT). In this mode, intelligent devices interact with each other on the basis of semantic services. Devices inside of the factory can achieve specific goals through self-organization. Zuehlke (2010) explained the concept with four dimensions: technology, framework, security and human.

2.3. Smart Process Manufacturing

The research on the Smart Process Manufacturing (SPM, 2010) has been conducted by the Engineering Virtual Organization (EVO). The EVO developed the roadmap of Smart Process Manufacturing and defined the SPM as: an integrated, knowledge-enabled, model-rich enterprise in which all operating actions are determined and executed proactively applying the best possible information and a wide range of performance metrics.

2.4. Industry 4.0

Industry 4.0 is based on the Cyber Physical Systems (CPS), and realized the novel manufacturing method (Industrie 4.0 Working Group, 2013). The CPS is that the devices are connected to the Internet, which makes them have the ability of computing, communication, accurate control, remote coordination and autonomy (Håkansson and Hartung, 2014). Therefore, the CPS realized the fusion between the virtual cyber world and the real world. The core of the Industry 4.0 is that a highly flexible, personalized, digital smart manufacturing pattern which was established by the real-time web and effective communications among people, equipment and products. In this mode, the production process becomes more distributed, and scale effect is no longer the key factor of industrial production; the product becomes more specific, and the future product will be produced in the custom-made pattern; and the users will participate in the production throughout the whole process.

3. Research progress in smart factory of petrochemical industry

3.1. Modeling and Simulation

The modeling and simulation of enterprises is a very important way to research on these entities, and it can also provide strategies for the enterprises' operation and management. Since the manufacturing process of petrochemical is usually very complicated, many key technological parameters cannot be obtained directly, the producing systems are also multi-scale in time. It is an indispensable method to have a better understanding of the whole production process with the development of models and simulation systems. In the early period of the research of smart factory, Pei and Rong (2005) came up with a smart factory simulation platform based on Matlab, which is the prototype of the smart factory. Zhang and Rong (2005) put forward an enterprise logistics balance layered modeling theory according to the ISA-95 standard, which was also used to develop the decision support system of smart factory. Zhu et al. (2013)conducted the research about the information integration of smart factory and put forward an information integration solution in the multi-scale perspective. Qi et al.(2013) came up with a four-storey framework for modeling and simulation. This method was used to construct the multi-layered and modular simulation systems.

3.2. Intelligent Control

Intelligent control is derived from conventional control, which is used to deal with the complex processes that cannot be controlled by traditional methods. The intelligent control systems mainly have the following characters: learning function, adaptive function and organizing function (Sun, 2007).

Bhuvaneswari et al. (2012) used the artificial neural network to maintain the pipelines and make fault diagnosis of them. Monedero et al. (2012) developed a decision-making system based on data mining technology and kernel of neural networks, which is used to make predictions for future optimization. The test results showed that this decision system can help reduce about 7 % energy consumption. The system will be piloted in the petrochemical industry. Sa'idi et al. (2014) built a Risk-based maintenance model through fuzzy logic method, and used this model to conduct the risk assessment of failures in Abadan oil refinery, Iran. Yüzgeç et al. (2010) optimize the control operation of the short-term plan of the petroleum refining using the Model Predictive Control method.

3.3. Intelligent Optimization Algorithms

The research of optimization for petrochemical engineering is quite significant, which mainly includes global optimization methods and heuristic methods. These methods are intriguing interest for researchers at current time, especially applicable for the complicated that cannot be dealt with by tradition approaches (Yu, 2007).

Kadambur and Kotecha (2015) optimized the production plan of petrochemical industry based on Teaching-Learning-Based-Optimization algorithm. Compared with traditional methods, this approach can increase the profit about 8.16 %. Zhou et al. (2015) optimized heated oil pipeline based on Particle Swarm Optimization-Differential Evolution method, which can save 17.59 % of energy cost in the application of 2640 m^3/h oil transfer. Lavric et al. (2005) used Genetic Algorithm to optimize the conversion rate of hydrogenated waste to hydrogen. By using this algorithm, an oil refinery factory in Iran can increase 22.6 % hydrogen products and save about 1.9 million every year. Ramteke and Srinivasan (2011) solved the refinery crude oil scheduling problem by combining the Genetic Algorithm and Graph-based Representation method. Khosravi et al. (2015) optimized the parameters of shell and tube heat exchangers to maximize the thermal efficiency by using three methods: Genetic Algorithm, Firefly Algorithm, and Cuckoo Algorithm.

4. The definition and framework of smart factory in petrochemical industry

On the basis of the above study, in the context of the petrochemical industry, we believe that smart factory in petrochemical industry is operational excellence as the goal, through the operational management of the whole process, with a high degree of automation, digitization, visualization, modeling and integrated refining chemical factory, which is the direction of future development of the petrochemical enterprises. Through the revolution of technology and business, the enterprises could have the outstanding capabilities of perception, prediction, interoperability, analysis and optimization. The smart factory mainly contains six core business, four capabilities, and two supporting systems. The framework of smart factory in petrochemical industry can be shown in Figure 1.

Moreover, the factors of smart factory in petrochemical industry consist of characteristics, capabilities, key business areas, intelligent application fields and key technologies. The details are presented in Table 1.

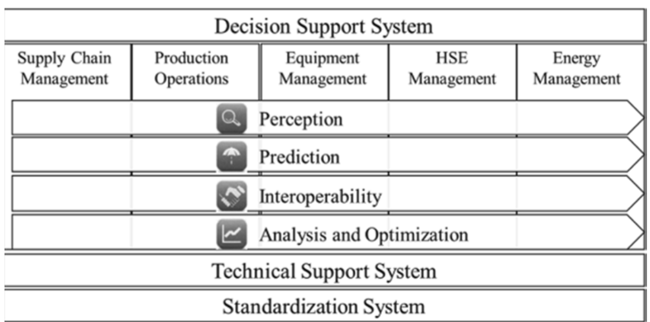

Figure 1. The framework of smart factory in petrochemical industry.

Table 1. Factors of the smart factory in petrochemical industry.

Factors	Descriptions
Characteristics	Digitization, Visualization, Modeling , Integration , Automation
Capabilities	Perception, Prediction, interoperability, Analysis and Optimization
Business Areas	Production Operations, Equipment Management, Energy Management, HSE Management, Supply Chain Management, Decision Support
Intelligent Application Fields	Business Intelligence, Manufacture Intelligence, Control Intelligence
Key Technologies	Optimization Technology, Artificial Intelligence, Control Technology, Information Technology, Petrochemical Technology

5. Conclusions and future researches

Establishing the smart factory is the important measure to handle the shortage of the gas and oil resources, the update of the oil quality, the optimization of industrial structure, the fierce competition in the global market, energy conservation and emission reduction, and environmental protection. The prospects of the smart factory are listed as below:

For equipment, traditional manufacturing units will be gradually changed to be the smart manufacturing units which have capacity of state acquisition, perception and can make intelligent predictions, optimizations and decisions; the smart control systems can optimize multi-devices, conduct self-study and -organize; the industrial robots are also used in the harsh conditions of the petrochemical production processes.

For technology, the knowledge based on analysis of the big data will be developed, which can help realize the combination of the massive information of heterogeneous perception; the technology of the combination of virtual reality and visualization will be widely applied in the petrochemical field; the modeling technology of complex systems, collaborative optimization technology etc. will make great progresses; the molecular technologies and ‘green’ system engineering will be spread in this industry.

For business, the construction of the smart factories in petrochemical industry can be divided into three process domains: production operations, petrochemical supply chain and whole lifecycle management.

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