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Research
Smart Process Manufacturing—Perspective

Smart Manufacturing for the Oil Refining and Petrochemical Industry

Zhihong Yuan [a], Weizhong Qin [b], Jinsong Zhao [a,*]

[a] Department of Chemical Engineering, Tsinghua University, Beijing 100084, China
[b] China Petroleum and Chemical Corporation Jiujiang Company, Jiujiang 332004, China

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ABSTRACT

Smart manufacturing will transform the oil refining and petrochemical sector into a connected, information-driven environment. Using real-time and high-value support systems, smart manufacturing enables a coordinated and performance-oriented manufacturing enterprise that responds quickly to customer demands and minimizes energy and material usage, while radically improving sustainability, productivity, innovation, and economic competitiveness. In this paper, several examples of the application of so-called "smart manufacturing" for the petrochemical sector are demonstrated, such as the fault detection of a catalytic cracking unit driven by big data, advanced optimization for the planning and scheduling of oil refinery sites, and more. Key scientific factors and challenges for the further smart manufacturing of chemical and petrochemical processes are identified.

1. Introduction

Advanced or smart manufacturing has recently been gaining increasing attention from the academia and industry in major economies. For example, Germany's Industry 4.0, which integrates resources, information, materials, and people to formulate a cyber-physical system, has been the priority of many enterprises, especially those that are small and medium-sized. In the United States, the Smart Manufacturing Leadership Coalition (SMLC), which has its headquarters in Los Angeles, California, leads the new Smart Manufacturing Innovation Institute, in partnership with the US Department of Energy [1]. Aiming to spur advances in smart sensors and digital process controls, which can radically enhance the efficiency of advanced manufacturing in the United States, the SMLC brings together a public-private consortium of nearly 200 partners from the academic, industrial, and non-profit arenas, and brings in over 140 million USD from these members. Unlike the United States and Germany, which have developed industries, China is in its developing stage. Many of the control/management systems and engineers in China are still stuck at the level of Industry 2.0. Therefore, in order to address China's national conditions and the gap between national and developed economics, the Chinese government launched a strategy called Made in China 2025 in 2015 [2]. Smart manufacturing is regarded as the central element in the Made in China 2025 strategy. Both Industry 4.0 and smart manufacturing focus on transforming the industrial sector into a connected, information-driven environment, in which production systems and supply networks can be optimized via real-time and customer-oriented internal vertical integration within smart factories, horizontal integration within upstream and downstream enterprises, and end-to-end integration from the supply chain to the customers.

Process systems engineering (PSE), which has played an essential role in facilitating advanced chemical processing and production since the 1960s [3], will play a key role in achieving smart manufacturing in oil refineries and petrochemical plants by encompassing the following advances in the processing unit, the plant, the enterprise, and the supply chain:

- Advanced sensing and instrumentation;
- Real-time flowsheet optimization and control under uncertainty;
- Green molecular design for high-value-added products;
- Adjustable big data analytics for process optimization, monitoring, and management;
- Advanced hardware and software platforms; and
- Predictive modeling and simulation technologies.

It should be noted that Fig. 1 merely highlights the key features of smart manufacturing from the perspectives of PSE, rather than

* Corresponding author.
E-mail address: jinsongzhao@mail.tsinghua.edu.cn

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providing the framework of smart manufacturing. To our knowledge, smart manufacturing should combine information, technology (beyond PSE technologies), and human ingenuity in order to bring about a rapid revolution in the development and application of manufacturing intelligence, and to improve agility, flexibility, productivity, and quality. This paper briefly outlines examples of the application of so-called "smart manufacturing" at the China Petroleum and Chemical Corporation (Sinopec).

2. Brief overview of smart manufacturing at Sinopec

In China, Sinopec is a pioneer in the launching of smart process manufacturing. With the goal of smart manufacturing, Sinopec has established four demonstration projects since 2012: smart petrochemical pilot units (including Jiujiang, Zhenhai, Maoming, and Yanshan), an integrated business-management platform, an information technology shared-service center, and a mobile application [4]. Through almost four years of construction, great changes have taken place in the selected four smart pilots in terms of automation, digitalization, and visualization. For example, advanced control is now available for over 90% of all processes in these four pilots and productivity has improved by more than 10%. Production optimization has been shifted from off-line optimization to on-line integrated optimization.

Fig. 2 illustrates a general integrated optimization platform currently running at Sinopec Jiujiang Company. Based on existing commercial software such as a manufacturing excution system (MES), enterprise resource planning (ERP), and a laboratory information management system (LIMS), flowsheet optimization, planning, and scheduling are integrated. At Maoming and Yanshan, integrated real-time optimization and advanced process control have achieved profit-oriented closed-loop optimal running for ethylene production. Due to obvious improvements in the yields of ethylene and propylene, the overall incomes for Yanshan and Maoming have improved by 25.12 million and 41.94 million CNY per year, respectively. In addition to the implementation of an integrated optimization framework and platform, big data analytic technologies and tools have been studied and implemented for abnormal event management. For example, big data (i.e., data size of around 50 TB) analytics have been utilized for production analysis and early warning for fluidized catalytic cracking units and reformers. Not only can big data analytics find new root causes, but they can also predict an alarm in advance.

Some experts claim that Sinopec has formulated a so-called "version 1.0 of smart manufacturing." However, as described above, the activities at Sinopec simply collect and integrate existing commercial optimization and simulation software, and include few new scientific methods or tools. In addition, no evaluation criteria exist that can be used to assess what smart manufacturing actually is. In other words, once true smart manufacturing has been implemented, it will fundamentally change the ways in which products are invented, manufactured, shipped, and sold. To some extent, there is still a very

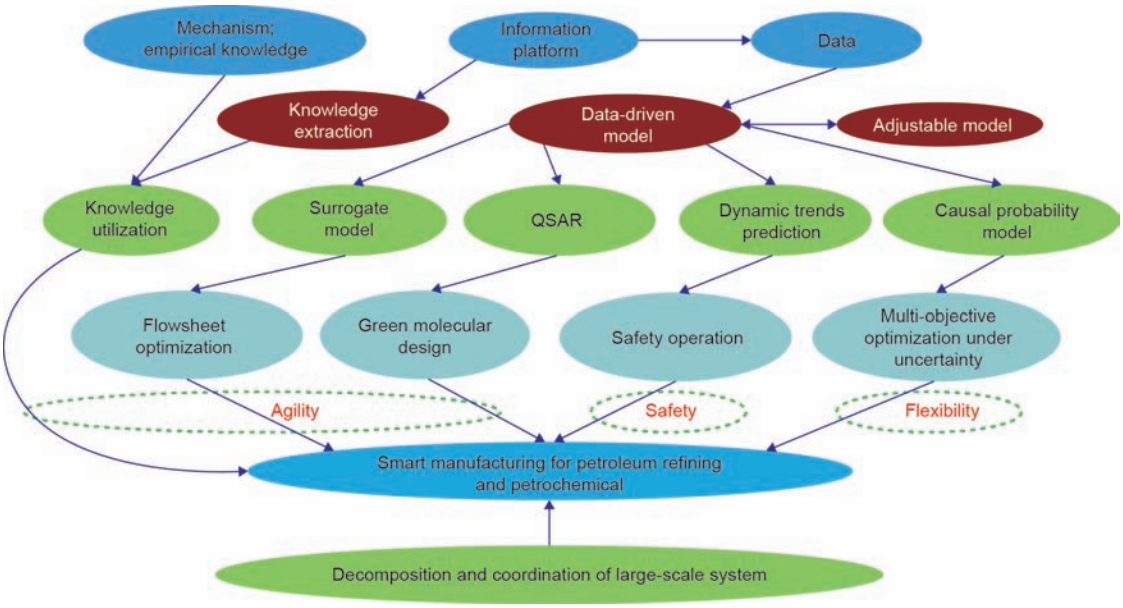

Fig. 1. Key features of smart manufacturing for the oil refining and petrochemical industries. QSAR: quantitative structure-activity relationship.

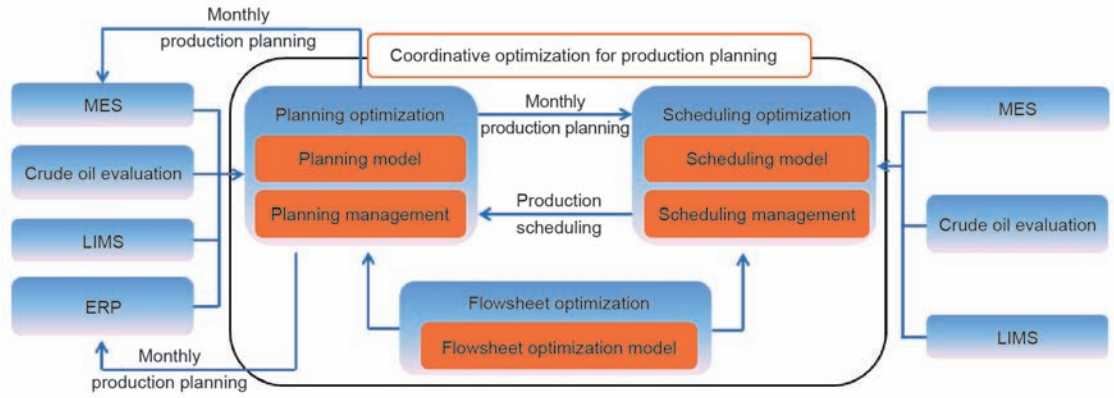

Fig. 2. The integrated optimization platform at Sinopec Jiujiang Company.