Perspective

Chemical Engineering in China: Past, Present and Future

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Introduction

The modern chemical industry experienced its genesis in the 19th century, and rapid development in the 20th, thereby achieving significant impact on the progress of human civilization. The Solvay process in 1870s marked a milestone in the deployment of continuous processes with integrated plant-wide considerations, while the commercialization of the ammonia synthesis process in the 1920s marked the first science-based landmark process in the modern chemical industry. Subsequent milestones were made possible by the successful application of techniques such as fluidized catalytic cracking in the refining industry, solvent extraction in the nuclear fuels industry, precision separation in the production of heavy water, submerged culture of microorganisms in the mass production of penicillin, etc., which all occurred in the 1940s. At the end of 1960s, the integration of chemical process systems engineering methodologies and computer control techniques established the foundation for the large-scale modern chemical enterprise. Advances in conceptual/biological design, operation and control of prokaryotic and mammalian biochemical processes, and synthesis techniques for new materials such as ultra-pure semiconductor materials and nanomaterials in the 1990s, have been at the core of an exploding high-tech chemical industry we have witnessed in the last 30 years.

Along with the global development in chemical engineering, the Chinese chemical industry also experienced major changes in the past century. As a large country with 1.3 billion people, the huge demand for basic and specialty chemicals led to broad market prospects, and, therefore, facilitated the fast development of the chemical industry, and promoted the advancement of education, research and development in chemical engineering.

It must be acknowledged, however, that there is a fundamental difference in the rate and the modes of overall development in chemical engineering between China and the developed countries. As one of the backbone industries that supported the rapid growth of Chinese economy, the chemical industry in China and its related education and research activities, for historical reasons underwent fast development only in the past 30 years, compared to a century-long progress in the developed countries. At present, China has excellent opportunities for closing the gap with the rest of the world, but also faces immense sustainability challenges in terms of energy, resources, and the environment. At the same time, industrial development requires a large supply of highly educated chemical engineers and enhanced capabilities in research and development. The objective of this Perspective is to provide a brief account of the historical development, present challenges, and future trends in the Chinese chemical industry and the discipline of chemical engineering.

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Beginnings of the Chinese Chemical Industry

Until the 1980s, the chemical industry in China was still in its infancy. In light of the basic demand of feeding up to 20% of the world's population (1.3 billion) using only 7% of the world's arable land, the chemical industry, naturally, focused its attention in the production of chemicals (fertilizers, pesticides, herbicides) to support rapid expansion of Chinese agriculture. However, while chemical fertilizers should have ensured the required increase in the crop yield per unit area, especially in the Loess Plateaus, China's main farmlands, limited by the low levels of engineering and technological foundations underpinning the chemical industry, and the inadequate levels of engineering education at the time, the amount of produced fertilizers did not meet the demand, their production caused heavy pollution and involved a wasteful utilization of resources.

Simultaneously, the chemical industries involved in manufacturing acids (e.g., H_2SO_4, HCl, HNO_3), and alkalis (e.g., NaOH, Na_2CO_3) increased their capacity in order to meet the basic requirements of the paper, glass, and nonferrous metal industries, among others. In order to balance the large

Table 1. Production Volume for Major Chemical and Petro-chemical Products ($\times 10^4$t)

	Product	2000	2005	2006	2007	Jan-Jun 2008	World Rank
1	Fertilizers	3091.3	4802.5	5168.8	5696.1	3001.5	No.1
	Nitrogen	2398	3579	3782.3	4187.1	2227.4	No. 1
	Phosphate	663	1075	1158.2	1256.7	652.1	No. 1
	Potassium	30.3	148.5	225.7	249.6	145.4	
2	Sulfuric acid	2365	4462	4808.8	5390.7	2663.1	No. 1
3	Soda	834	1421	1566.6	1771.8	967.43	No. 1
4	Methanol	199	536	758.5	1076.4	541.1	No. 1
5	Refined oil	20238	28622	30713.6	32679.3	16947.3	No. 2
6	Ethylene	470	755	930.4	1047.7	535.9	No. 2
7	p-Phthalic acid	202	556	665	933	500	
8	p-Xylene	130	223.7	279	350	180	
9	Synthetic rubber	83.6	163.2	195.8	221.5	116.2	No. 3
10	Synthetic resins	1079.45	2141.9	2593.7	3037.6	1613.7	No. 2
11	Engineering plastics	3.7	19.7	34.9	55.6	35	
12	Caustic soda	668	1240	1503.7	1759.3	989.3	No. 1
13	PVC	240	649	811.1	971.7	487.6	No. 1
14	Calcium carbide	340	895	1251.6	1481.9	755	No. 1
15	Pesticides	64.8	104	139.2	173.1	101.1	No. 1
16	Tires	12158	31820	45390	55648	28065.6	No. 1

amount of byproduct chlorine (Cl_2) from a caustic soda industry, based on the salt electrolysis processes, the PVC industry was thereafter established. It must be noted that the ammonia synthesis and PVC industries both adopted processes starting from coal as the major feedstock.

Rapidly growing and expanding industrial experience and especially fast improving and diversifying professional education from the initial career stages, soon became cornerstones for the subsequent development of Chemical Engineering in China, which nevertheless lagged behind the world at that time.

Fast Development of Chemical Engineering in the Past 30 Years

Chemical and petrochemical industries

Since the early 1980s, China began to import mature petrochemical process technologies from abroad. As a result, at this time, a number of integrated industrial complexes have been successfully established in China. In particular, the overall strength and competitiveness of the petrochemical industry have been significantly enhanced. The average annual rate of increase of product value at current prices, industrial added value and sales revenues are 21.25%, 18.28% and 21.50%, respectively, which are much higher than the rates of increase of GDP in China and the developed countries during the same period.

Today, China is the major manufacturer of chemical and petrochemical products in the world (see Table 1). The production volumes of several key chemical products are among the highest in the world, including the following: synthetic fibers, chemical fertilizers, soda, caustic soda, and PVC, in which the Chinese production is the highest in world; crude oil processing, ethylene, and synthetic resins, etc., where the Chinese levels of production hold the second position. The current production of petroleum refinery products, nitrogen fertilizers, phosphate fertilizers, soda, pesticides, and caustic soda has satisfied internal demand, while the production of inorganic salts, automobile tires, and others, and has exceeded domestic demand. In contrast, the production of ethylene, synthetic materials, chemical fiber materials, potassium fertilizers, and methanol does not satisfy domestic needs and is heavily supplemented by imports.

Along with the expansion of gross production capacity in basic chemicals, technical indicators of capital efficiency, such as the plant capacity in the petrochemical industry, have been continuously improving. In 2008, 13 Chinese refineries had production capacity larger than 10 Mt/a, each, for a total production of 136 Mt/a; 42.6% of the total production in China. Plant capacity for ethylene production has increased to more than 450 kt/a, for each petrochemical plant. At the same time, several novel refining technologies were introduced for clean gasoline production with high-added value olefin byproducts. For example, a two-stage fluid catalytic cracking (FCC) technology, combining the functions of refining and propylene production, was developed by researchers in the Chinese Petroleum University and has been successfully commercialized. The downer reactor, the so-called 21st century refining reactor technology, was first demonstrated in 2003, in Ji'nan refinery (SINOPEC) at a capacity of 150 kt/a. The essential idea in this technology is to utilize the favorable plug flow pattern and uniform flow structure in the downer reactor in order to achieve limited over-cracking and improved selectivity in a refining process. The corresponding research was carried out over a period of about 30 years in the Fluidization Laboratory of Tsinghua University (FLOTU).[1–3] The demonstration unit implemented the flexible operation of a coupled riser and downer design by changing the feed positions and using high-severity operational conditions to intensify the cracking of petroleum cuts.

Increased productivity, energy savings and emissions reduction have become the central goals of the petrochemical industry and are driving science and technology development. In order to fulfill the national targets in China's 11th five-year plan (2006–2010), the energy consumption quota in the petrochemical industry must decrease from 3.23 in 2005 to 2.58 in 2010, in terms of the standard coal consumption (i.e., the amount of heating value by different fuels equivalent to 7000 kCal/kg of standard coal) for power generation per 10 k RMB GDP. Obviously, major effort is required to meet this goal; a major driver for the advancement of the petrochemical industry and a visible measure in reducing CO_2 emissions to address climate change.

Limited resources have become a critical constraint to the current development of Chinese petrochemical industry. For example, in 2007 petroleum production in China was about 18.7 Mt, while the imported amount was about 16.3 Mt, and the apparent consumption was 34.6 Mt. Thus, the degree of external dependence was about 45%, and this figure has continued to increase in the last three years.

Coal chemical industry

In 2006, coal supplied 70.2% of the energy consumed in China, with 23.5% coming from oil and natural gas, and 6.3% from other sources. This is in sharp contrast with the energy consumption structure in the rest of the world: Coal, 28.4%; oil and natural gas, 59.5%; other sources, 12.1%. To match the chemical industry's development with the structure of energy production/consumption in China, coal-based chemistry has been one of the major directions in the development of chemical industry. A large-scale clean coal project has become the focus of development efforts, with significant technological breakthroughs anticipated in its major processes. In addition to the urea industry, the production of methanol based on coal conversion is increasing dramatically, e.g., about 11 Mt in 2007. Currently, the consumption of methanol involves the production of formaldehyde, acetic acid, methyl *tert*-butyl ether (MTBE), alcohol ether fuel, pesticides, methylamine, and others. The extended range of methanol products, such as polyoxymethylene (POM), poly(-methyl methacrylate) (PMMA), pentaerythritol, cellulose acetate, organosilicon, etc., are also undergoing rapid development. The new technologies in the coal chemical industry such as MTO (methanol to olefins), MTP (methanol to propylene), MTA (methanol to aromatics), and coal to SNG (substitute natural gas), are being developed at pilot-plant scale units, which frequently rise to units of industrial-scale production. Moreover, the pilot use of methanol and dimethyl ether (DME) as alternative fuels aims to partially mitigate the urgent demand for oil and has been tried in several cities in China. Since coal is an abundant natural resource in China, it is expected that a coal-based chemical industry will continue to play a pivotal role in China's economic development and offers bright prospects for the future.

Up to this time, more than 95% of China's energy resources have been domestic. For exported products such as the coke, calcium carbide, ferrosilicon, ferroalloy, aluminum ingot, polycrystalline silicon and so on, the scales of production are very large, but the added value in these products is very low. Since the amount of energy per unit of product needed in the production of these materials is rather large, export of these materials implies a kind of embedded energy export from China. It is estimated that during the period from 1997– 2007 the total amounts of imported and exported energy in China were roughly balanced. However, due to the high rates of industrial development, China's eco-environmental burden has been increasing at substantial rates by heavy pollution.

Fine chemicals and materials manufacture

Concurrently with the aforementioned developments in the petrochemical and coal-based chemical industry, the production of fine chemicals has been also advancing with high rates of growth. In 2006, the produced value of fine chemicals in China was about 500–550 billion RMB, with the total volume of production at about 30 Mt/a, not including pharmaceuticals and veterinary drugs (see Table 2).

However, it should be noted that these fine chemicals are not high-end products of high added value, and were produced through technologies of rather low-level scientific and engineering content. In addition, the R&D capabilities of the corresponding companies are rather weak in the area of fine chemicals and cannot meet the demands associated with mass production of fine chemicals in the future. This weakness creates excellent opportunities for the collaboration of

Table 2. Production of Fine Chemicals (2006)

Product	Production ($\times 10^4$ tons)	Exports ($\times 10^4$ tons)	Exports as % of global trade
Dyes	75.37	25.16	40%
Pesticides	137.1	39.8	40%
Citric acid and its compounds	—	57.1	80~85%
Paints	597.3	—	—
Lactic acid and its compounds	—	3.1	35~40%
Food additives	290~300	—	—
Saccharin and its compounds	—	1.6	80%
Lysines	—	14.3	30%
Glutamates	—	20.7	50%
Cholines	—	10.04	50%
Paper chemicals	105~115	—	—
Plastic additives	230~240	—	—

the specialty chemicals Chinese companies with foreign countries (companies; chemical, technology developing, product formulators, etc.), in the form of direct investments from abroad and collaborations on the development of certain technologies and products. A similar situation exists in the advanced materials sector of the industry.

Innovations in clean energy and low-carbon techniques

Pollution control is one of the biggest problems associated with the fast development of the Chinese chemical industry. Detailed guidelines have been issued by the Chinese government, according to which the SO_2 emission and COD (Chemical Oxygen Demand) index should be reduced by 10% along with a stable and rapid growth of GDP in the next five years. Since the necessary flue gas desulfurization devices and the new sewage treatment plants, expected to support the targeted improvements, have already been constructed to a large extent, the desired targets should be achieved. At the same time it is fairly broadly accepted that the most rational route to implementing pollution control would be through innovative production technologies that lead to zero-emission process designs, especially for the coal-based segment of the Chinese chemical industry.

The ENN Group, a private enterprise in China, has established an advanced research center where it has been pursuing effective integration of novel technologies and engineering methodologies and in 2009 was able to realize coal-based, clean energy, zero-emission production technology at the pilot plant scale. Figure 1 shows the flow chart with the highlighted technologies in ENN Group's research center. It is anticipated that this integrated approach of low-carbon technologies will lead to the successful incorporation of solar

Table 3. Production of New Materials

Product/ Group of Products	Consumption in 2006 ($\times 10^4$ tons)	Demand in 2010 ($\times 10^4$ tons)
Polycarbonate	76	100
Polyoxymethylene	18	30
polybutylene terephthalate	11	15
Polyphenylene sulfide	0.6	0.8
Polyurethane materials	300	480
Polyamide	28	40
Modified polyphenylene oxide	3.8	6
Silicone monomer	55	100
F22	26	35
Teflon	2.7	3.5

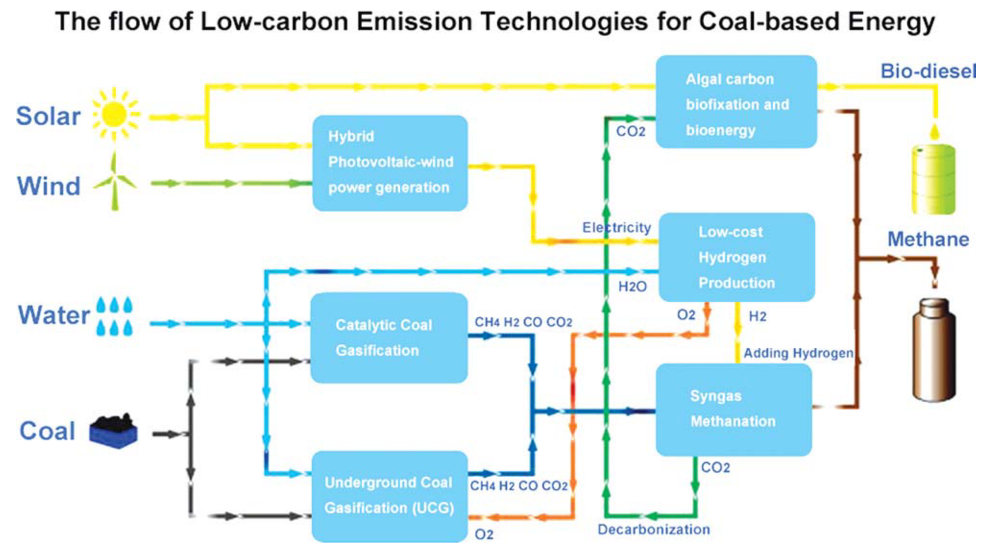

Figure 1. Coal-based low-carbon emission technology of ENN Group (www.enn.cn).

energy, wind energy, and biotechnology with the coal chemical industry, in order to provide an effective solution to the carbon dioxide emission problem. Furthermore, the underground processes based on steam-oxygen gasification, coal catalytic gasification and methanation technologies are directed toward the development of clean and low-carbon processes which convert dirty coal to clean and low-cost energy.

Another series of innovative technologies are targeting the clean production of PVC resins. In 2009, the annual production of PVC in China was about 12 Mt and was mainly based on the conventional carbon calcium route, which uses mercury as the major component of the catalyst that converts acetylene and HCl to VCM (vinyl chloride monomer, CH_2CHCl), and causes severe pollution to the environment in terms of waste gas, dust/residue, and effluents of water and mercury. Since the carbon calcium production method starts from the coal to coke process, the PVC industry is in fact one of the coal conversion industries with large volume of annual production.

As the first step to make acetylene from coal, coal pyrolysis to produce acetylene in thermal plasma reactor has been explored in China for the past 10 years. This is actually a well-known technology discovered[4,5] and developed[6,7] in the period 1960–80s, but not commercialized due to limited market demand in that period and the difficulties associated with continuous operation over long time periods of such high-severity process. In this process, pulverized coal is injected into hydrogen plasma of ultra-high temperatures and supersonic flow velocities of more than several hundred meters per second. The conversion of coal to the desired acetylene product takes place in milliseconds, with hydrogen, ethylene, methane, and CO, as the primary byproducts.[8–10] The attractive features of this process are: it is coal-based, clean, one-step conversion technology, without direct emission of carbon dioxide, and without the need for water as feedstock.[11] At present, a demonstration pilot plant with the plasma power input of 5-MW, including reaction, separation and the common facilities, has been successfully built and run for industrial testing by the Xinjiang Tianye Group. It is well-known that acetylene was the major feedstock for the synthetic chemicals' industry for many years.

Technological breakthroughs on the coal pyrolysis process using plasma would result in the revitalization of the acetylene industry, an attractive prospect considering the continuously increasing prices and comparative scarcity of oil resources.

Following the clean production of acetylene, a mercury-free process to synthesize VCM is being explored in China with financial support from the government and PVC-producing companies. Two reasons drive the development of mercury-free production technologies: eliminate the adverse pollution effects from production process effluents containing mercury; eliminate reliance on mercury whose world-wide resources are being exhausted rapidly. It is expected that this novel process would be successfully commercialized within five to 10 years. Successful completion of the aforementioned two novel process technologies would lead to the rewriting of production technology textbooks' chapter on the production of PVC, a production process that started from coal.

As a further extension to the PVC product chain, a novel gas–solid contacting process to make chlorinated PVC (CPVC) in a clean way has been under development, using cold plasma as the initiator of the chlorination process, which is quite distinct from the conventional aqueous-suspension method that produces significant amounts of unavoidable pollution. There are two important reasons for pursuing large-scale commercialization of chlorinated PVC. First, CPVC has many superior characteristics when compared to PVC, e.g., it is thermally more stable and superior as flame retardant, and as a result offers a product with higher net added value. Second, the production of CPVC utilizes excess chlorine gas from the chloro-alkali industrial production network and incorporates it into the solid-state CPVC resins; a net effect of great significance for the chlorine balance in China.

Figure 2 shows the vision of a future production network for the clean PVC production with several technology innovations in the core processes. In comparison with the

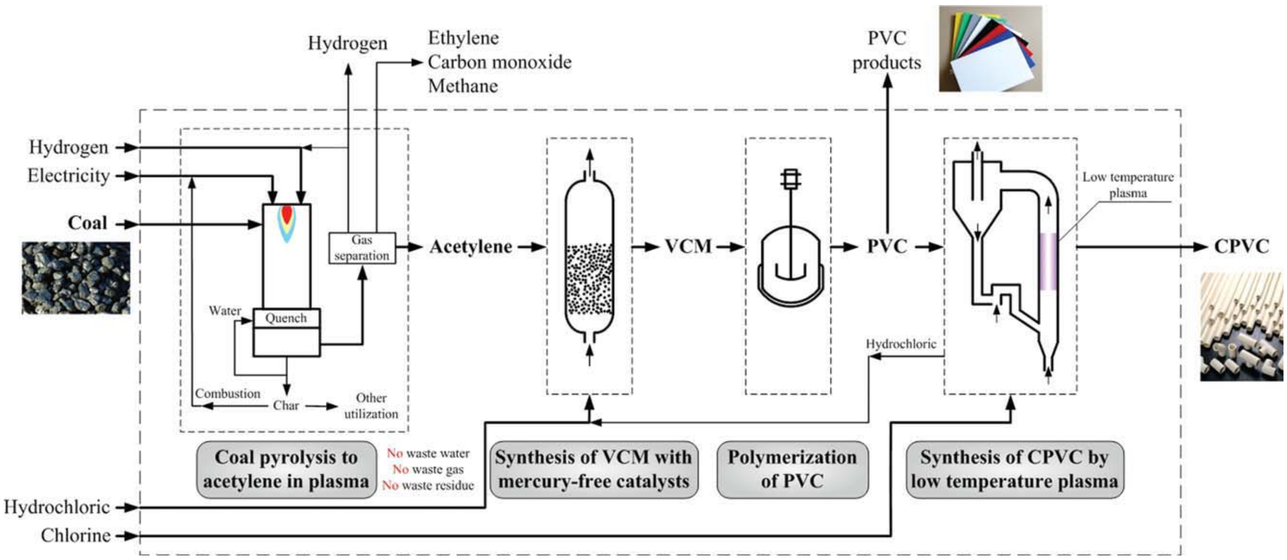

Figure 2. A future perspective of clean production of PVC.

conventional calcium carbide route, this series of novel technologies would be considered as the advanced industrial innovations equivalent to changing the *devil* to an *angel*.

The aforementioned two examples illustrate the guiding principle in present-day developments in the Chinese chemical industry; address ecological problems through technological innovation. This principle is shared by Chinese universities and is expressed by the scope and content of their educational and research programs. Typical example is the lead taken by Tsinghua University in establishing the Low-Carbon Energy University Alliance with Cambridge University and Massachusetts Institute of Technology (MIT). Furthermore, the Chinese government has taken active steps to encourage the establishment of industrial clusters, which through innovative integration of the production facilities can reduce the pollution impact of the cluster's net effluents, with more than a hundred eco-industrial demonstration parks established so far. Within the boundary of each eco-industrial park, the factories can optimally allocate the flows of materials, energy, effluent pollution streams, value streams and information streams. For example, the waste streams and waste heat in plant A can be utilized by plant B. In this manner, the industrial chain is extended, the network of integrated operations across different processing plants is expanded, and the whole system is well integrated to achieve the best efficiency. Through a series of planned programs, the idea of eco-industrial parks is presently scheduled to expand and cover many different areas of China. As a result, the underlying research issues have become popular topics of research engagement by chemical engineering academics in China.

Perspectives on Education and Research in Chemical Engineering

Future prospects in chemical engineering education and research in China are very bright: their expansion and growth, both in size and quality, being driven by the rapid development of the modern chemical industry in China.

Education

In 2007, about 2,073 universities and colleges (82.3% of the total) offered degree courses in engineering, with most of them offering degrees in chemical engineering. The number of newly recruited students per year for engineering degrees was about 891,000, which accounted for 31.6% of the total number of students enrolled in Chinese universities and colleges. From this point of view, China has the largest population of students in engineering education in the world, and since most of them offer degrees in chemical engineering, China has the largest population of chemical engineering students in the world. However, the role of chemical engineering as a discipline is not fully appreciated by students and their parents in China, a very troubling and incompatible reality to the rapid development of the national chemical industry. In 2004, DECHEMA carried out a survey with 2,158 students/engineers from more than 20 countries regarding their educational and professional career satisfaction with their major in Chemical Engineering[12] (Figure 3) 33% of the Chinese students/engineers indicated that they were not satisfied with their selection chemical engineering as their subject of study or discipline for professional career. This is the largest negative percentage among all student groups surveyed, by comparison of the negative responses from the US accounted for only 5%. The larger than usual negative attitude of students and professional chemical engineers may be attributed to the historical perception of the chemical industry in China: heavy pollution, severe working environment, safety, etc. Nevertheless, the survey has attracted widespread attention among Chinese university professors of chemical engineering, who have focused their attention on the question of how to encourage and guide excellent high-school students to the exciting world of chemical engineering science and technology and the pivotal role that the discipline plays, and will play even more in the

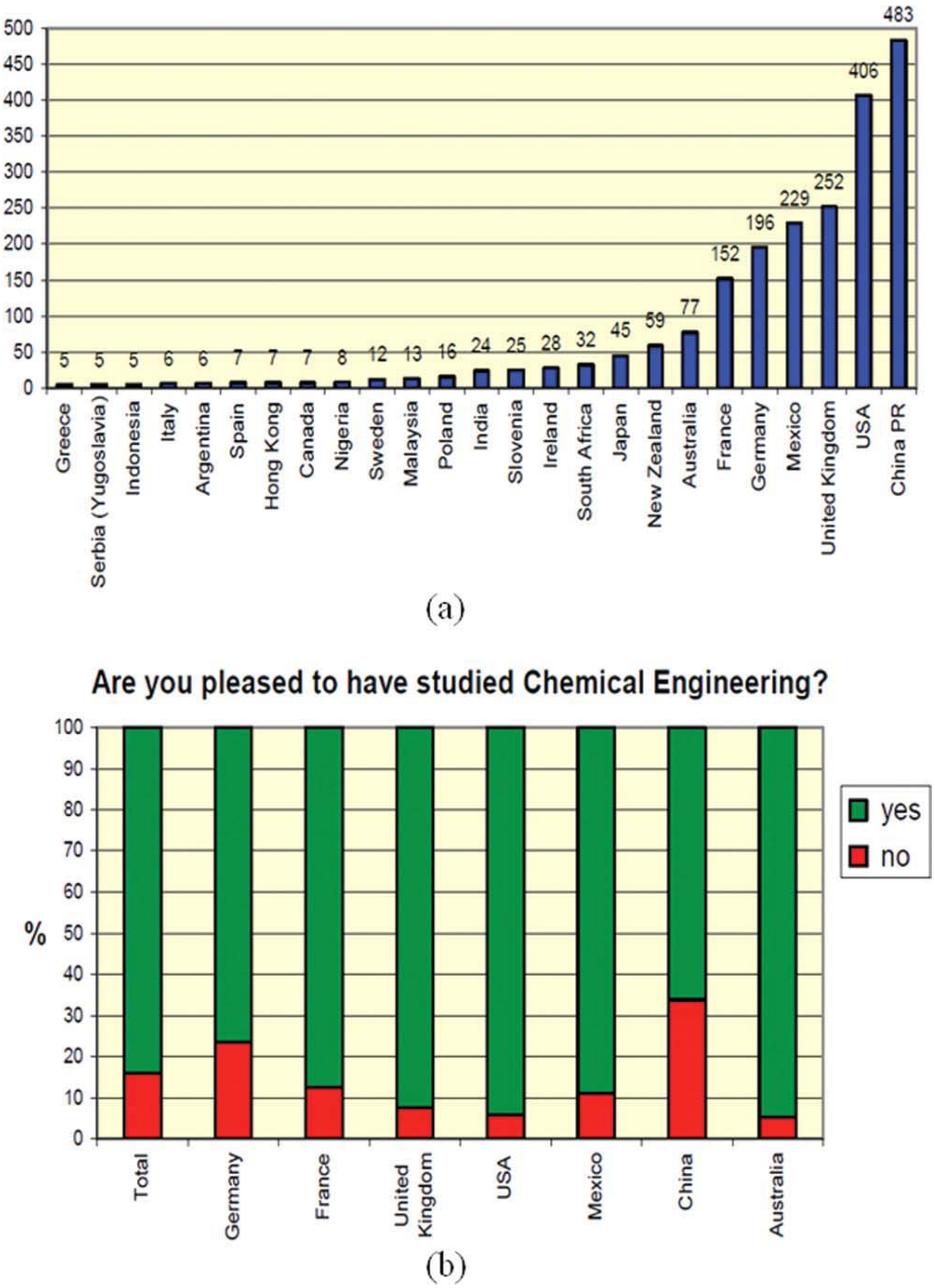

Figure 3. Survey by World Chemical Engineering Council "How does chemical engineering education meet the requirement of employment". (a) Participation of selected home countries, and (b) "Are you pleased to have studied Chemical Engineering" results of the Yes-No scheme. (http://www.dechema.de/chemengworld_media/Downloads/survey.pdf).

future, in advancing the economic growth and quality of life of the country at large. Besides utilizing the media, reading materials, and lectures to help change the public perception of the chemical industry, the experts also agree that it is essential to re-orient chemical engineering in the current era, giving truthful answers to students regarding what can be learned in chemical engineering, what kind of jobs can be pursued after graduation, and the impact they can have in modern technology and industrial practice. In other words, the educators must be able to show the scientific paradigms and provide realistic future perspectives to students.

In the 1920s, the paradigm in chemical engineering was defined by the concept of 'unit operations'. In 1950–1960s, it addressed the scope of chemical engineering science articulated by transport phenomena (momentum, heat, and mass transfer), thermodynamics, and reaction engineering. However, by the end of last century, none of the above definitions could provide a comprehensive summary of the nature of chemical engineering as a discipline. "Product engineering" was proposed as an alternative to the traditional concept of process engineering, which in turn brought new insights into the chemical engineering paradigm for chemical engineers. However, the product engineering concept did not possess a clear relationship with the historical chemical engineering paradigm, leaving significant gaps in relevance and consistency. To show the distinct characteristics of chemical engineering compared with other disciplines, Chinese professors proposed to define the paradigm as the *transfer and transformation of materials, energy and information*, which integrates simultaneously the three key elements of any chemical process and by extension of the chemical engineering discipline, namely, materials, energy and information. The proposed paradigm embodies the intense cross-currents and fusions between chemical engineering and other disciplines, such as chemistry, physics, mathematics, biology, etc. The apparent benefit of the proposed paradigm stems from the fact that the latest discoveries in other disciplines can be readily introduced to the chemical engineering discipline, allowing new areas to be defined/re-defined, such as biochemical engineering, biomolecular engineering, nanoengineering, systems engineering, materials-oriented chemical engineering, etc. In particular, such an approach allows the contemporary and future high-tech developments in these areas to become seeding points for further growth within the scope of the chemical engineering discipline. Fundamental knowledge can be readily embedded within the scope of a chemical engineering curriculum, and this in turn would attract the best students by enhancing their natural curiosity and enthusiasm for learning.

In parallel with the development of an exciting intellectual scholarly framework, chemical engineering possesses a strong foundation, that is, the chemical, materials, biological, biomedical industries it serves, which thereafter demonstrate the close relationship of the discipline with improving people's daily life. Working in chemical engineering, students have great opportunities to shape exciting career paths by becoming inventors and entrepreneurs and derive great satisfaction from professional success with impact. Such prospects would attract more students to the discipline of chemical engineering and would strengthen the future of the Chinese industry in chemicals, materials, biologicals, both in processes and products. In fact, it will allow chemical engineering to be seen as an innovation area, rather than simply as an engineering discipline.

Research and technology development

Historically, the Chinese never ignored the science and technology gaps in chemical engineering between China and the developed countries. However, the pressures for rapid growth from a lower level of technological infrastructure led to redundant and repeated technology imports, which in turn slowed down the development of domestic technologies in chemical engineering. For instance, more than 20 packages of the same process technology for synthetic ammonia and urea, with a capacity of 500 kt/a, were imported from overseas in the last century. Today, such policy is both unnecessary and counterproductive; China has made considerable progress in recent years and its future relies on differentiating technological competitiveness. Consequently, today, the national science and technology development strategy provides a guide to the needed technological demands within China. Thus, through a coordinated effort, universities carry out fundamental research within the scope of technological needs articulated by the chemical industry. The result has been a series of new technologies, which have fueled a revolution in the Chinese chemical industry. A strong manifestation of the success of this approach has been the extensive licensing of major technologies, developed in China, by chemical companies from advanced countries, including, among others: fluid catalytic cracking technologies with olefins as byproducts, deep catalytic cracking (DCC) processes, and large-scale gasification technologies using opposed multi-burner (OMB) gasifier.

The aforementioned competitive technological developments in the basic chemical industry are the direct result of rapid advances in the underlying Chinese infrastructure, both quantitative and qualitative, of fundamental research in chemistry and chemical engineering. In the 2007 report of the U.S. National Research Council (NRC), "International Benchmarking of the U.S. Chemical Engineering Research Competitiveness", a series of numerical data shows the 10-fold increase of Chinese publications from the 1990–94 to the 2000–2006 period. This increase is broadly distributed over all areas of both classical and contemporary chemical engineering research interests. Today the number of SCI-indexed peer-reviewed articles published by Chinese researchers is ranked third in the world. Furthermore, from the same NRC study, mentioned previously, along with the explosion in the number of Chinese publications in chemical engineering, the quality and impact of the publications has improved substantially. For example, during the period 1985–90 there was no Chinese publication in the top 100 most cited articles in chemical engineering. In the period 2000–06 there were 11.

However, despite all this progress it must be acknowledged that China still lacks core innovations with extensive and significant impact on the emerging areas of science and technology. Furthermore, the efficiency and success rates of technology transfer from R&D labs to commercial applications are still relatively low, an important question that merits serious scrutiny and further research. To overcome this weakness, the Chinese government has offered a series of incentives to encourage the establishment of research and development strategic alliances for new technologies, such as in iron and steel-related processes and products, new generation of clean coal technologies, and others. The basic idea is to promote the rapid implementation of technological innovations to pilot-plant scale units and then to industrial-scale commercialization of a technology.

Although the Chinese chemical industry is becoming a very important factor of the world CPI (chemical processing industries), one should remember that it is a very young industry, grown with explosive rates in the last 30 years, initially with large imports of process technology packages and gradually with homegrown technologies from Chinese university research efforts. Today, China, a country with the largest population in the world, must rely on her own abilities to innovate and establish advanced, sound chemical industry systems with a strong foundation in education, research, and development, in order to fulfill the national demand for sustainable development. China is open to the world, and this openness creates many opportunities for professional chemical engineers, from both China and overseas. In other words, China is developing economically with a global vision, but is acting locally. In some sense, China is creating a unique China model for social and economic development, which is different from that in Europe and North America. Opportunities and challenges are vast, attractive, and exciting, and offer synergistic interaction between China's development in the chemical industry and advancement in the discipline of chemical engineering in terms of education, research and development, and growth in professional effectiveness and satisfaction.

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