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doi: 10.2306/scienceasia1513-1874.2007.33(s1).051

ScienceAsia 33 Supplement 1 (2007): 51-55

From Chemical Engineering through Powder Technology to Nanoparticle Technology: Our Personal Experiences

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ABSTRACT: Chemical Engineering (ChE) was born out of the necessity to serve the chemical process industries. A convergence of two fundamental disciplines, chemistry and mechanical engineering, ChE has contributed tremendously to the rapid global growth of the chemical, petroleum and petrochemical process industries. Recently ChE has diversified into newly emerging fields such as Nanotechnology (NT) and Biomedical Engineering. Similarly, powder/particle technology (PT) offers very useful multi-disciplinary expertise, which has made distinctive contributions to the high-tech industries, thereby providing effective production of particulate materials, that are essential building blocks of countless products used in downstream industries and in our daily life. A logical extension of PT, nanoparticles and to a certain extent Nanotechnology have successfully aroused researchers in diverse fields to collaborate and share their advanced knowledge, experiences and facilities with the ultimate goal of bettering the living standards of our people and the prosperity of mankind. The present article summarizes the personal experiences of the authors in the development of ChE, PT and NT in Thailand, including some of their academic and technical contributions, as well as words of advice.

KEYWORDS: Chemical Engineering, Powder Technology, Nanoparticle Technology, Nanotechnology.

WHAT IS CHEMICAL ENGINEERING?

Chemical Engineering (ChE), a convergence of two fundamental disciplines, chemistry and mechanical engineering, was initiated almost simultaneously in MIT, USA, and UMIST, UK, about 100 years ago. ChE has contributed tremendously to the rapid global growth of the chemical, petroleum and petrochemical process industries. In general, ChE deals more with uncomplicated fluid handling and processing than with solid/powder handling and processing. Typical Unit Operations engaged by chemical engineers are Distillation, Solvent Extraction, Adsorption, Fermentation, and Drying[1]. Fundamentals in Thermodynamics, Kinetics and Reaction Engineering, as well as Transport Phenomena, play essential roles in the design and development of the various process equipments mentioned above. Process control and simulation also contribute to novel process development and optimization.

In Asia, Japan was among the first to introduce and adopt chemical engineering from the USA more than 70 years ago and subsequently powder/particle technology from the UK and Germany about 50 years ago. The Society of Chemical Engineers, Japan (SCEJ) and the Society of Powder Technology, Japan (SPTJ) are undisputedly among the world's top professional societies in their respective fields.

In Thailand, a Department of Chemical Technology was established in the Faculty of Science, Chulalongkorn University (CU) in 1959 via the initiative of Professor Dr. Tab Nilanithi[2]. In 1961, an Industrial Chemical Engineering (ICE) option was offered in the Department of Industrial Engineering, Faculty of Engineering, CU[3]. With the strong growth of our chemical process industries, the ICE option became a separate ChE department in 1975. These two leading departments have so far produced more than 3,000 graduates from Bachelor to Doctoral levels. Subsequently some 20 ChE departments have been established in major public and private universities in Thailand, which produce about 900 and 200 chemical engineers annually at the undergraduate and graduate levels, respectively. Recently, these ChE departments have diversified their academic staff and facilities into specialized fields such as catalysis, biochemical, polymer engineering, process systems engineering, particle and material technology, followed by nanotechnology and biomedical engineering. In addition to the decades-old ChE Division of the Engineering Institute of Thailand, a Thai Institute of Chemical Engineering and Applied Chemistry (TIChE) was officially inaugurated around 10 years ago.

History of Powder Technology (PT) in Chulalongkorn University

In 1993, the first author W.T. and his colleagues in several major universities and the industry set up Thailand's first Thai Powder Technology Center (TPTC) in CU to promote Powder Technology, with strong support from the Association of Powder Process Industry and Engineering, Japan (APPIE) and the Society of Powder Technology, Japan (SPTJ). A few years later, W.T. and his colleagues set up a Particle Technology and Material Processing (PTMP) Laboratory in the ChE Department, CU, to create knowledge and train young researchers, as well as conduct R&D with an emphasis on Particle Technology, Materials Processing and applications.

In 1998, a Thai Association for Particle Industries (TAPI), the first legally registered non-profit association in Particle Technology, was established by the key members of TPTC along with a number of Thai academic institutions and corporations. TAPI's stated mission includes technical consultation, research implementation, and presentation/ publication of research results, as well as promoting technological advancement, standardization systems and standard methods in PT industries.

With encouragement from CU, TPTC and PTMP combined their activities into a Center of Excellence in Particle Technology (CEPT) in 2002 in order to excel in conducting research and generating fundamental knowledge in particle technology, as well as contributing to the development of novel products and apparatuses, including relevant pollution control technology. Over the past few years, CEPT has strategically extended research areas to cover nanomaterials, for example, production of carbon nanoparticles, nanotubes, mesoporous activated carbons and carbogels. In addition, researchers in CU and other institutions, such as Kasetsart University, KMUTT and KMITL, have proactively participated in CEPT's activities, for instance conducting collaborative R&D, setting national research directions in specific fields, including National Nanotechnology Strategy, generating high-caliber PT engineers to serve our industrial needs, and providing consultancy services to the industrial sector, especially Small & Medium Enterprises. In August 2004, C.T. succeeded W.T. as head of CEPT after the latter was appointed the first director of the National Nanotechnology Center (NANOTEC) under the National Science and Technology Development Agency (NSTDA).

Extension of Powder Tech to the Emerging Nanoparticle Technology (NPT)

Powder/particulate material is said to represent a pseudo 4th phase, a hybrid between fluid (gas, liquid) and solid. For example, gas-solid suspensions, liquid-solid suspensions, powder-powder mixtures and gas-liquid-solid suspensions are employed in various industrial operations, such as fluidized bed, pneumatic/ hydraulic conveying, three-phase flow with particles, and polymer compounding. In fact, PT deals with a wide variety of particulate materials, from sub-micrometers in size to large grains and gravel, from liquid mist or droplets to gas bubbles as well as solid agglomerates and aggregates[4]. PT is closely entwined with progresses in the medical, biological, pharmaceutical, food and agricultural sciences, and civil and other engineering fields. It is reasonable to say that PT also contributes to innovative and evolutionary technology that plays a crucial role in our daily life.

In the real world, as particles get smaller and smaller, they tend to aggregate, coagulate or agglomerate due to enhanced surface interactions. At the same time, under the action of certain force fields, the particles might deagglomerate or even become fractured. It is well known that particles of different physical properties such as size, density, and/or shape tend to segregate. Fibrous materials tend to become entangled. Therefore new behavior and characteristics must take account of the size, shape, chemical, thermal and electrical properties of the particles, their coating layers and the surrounding fluid.

Although PT is a well established discipline in advanced industrialized countries, PT in Thailand was rarely recognized for its roles and contributions until TPTC was established in CU in 1993. As the particle size of interest became increasingly smaller, it naturally entered the nanometer realm of nanotechnology. The color, melting point, chemical reactivity etc. of nanoparticles are changed. In 2000, the US National Nanotechnology Initiatives (NNI) suddenly ignited intense interest in nanotechnology world-wide. Soon afterwards, NSTDA established Thailand's National Nanotechnology Center (NANOTEC) at the initiation of Professor Pairash Thajchayapong with key contributions from W.T. However, it should be noted that Thailand is several years to some decades behind the leading countries in nearly all aspects of S&T, including the number of researchers, research budgets and facilities.

There is no doubt that the production of nanoparticles and related functional materials is closely related to PT. This leads to the expectation that nanotechnology (NT) along with PT will serve as an effective means to improve the quality of life. In fact, the near-term results of synergism between PT and NT are novel products and/or innovative processes with new or enhanced functionality for real-life applications. For instance, Nano Silver, Nano Gold and Carbon

Nanoparticles have turned into essential building blocks for numerous down-stream industries.

In short, PT has long played, and will continue to play, an important role in the growth of the traditional and high-tech industries in Thailand. As witnessed in all developed countries, PT will be indispensable to the sustainable development and success of existing and new hi-tech industries in Thailand. Meanwhile, as an emerging revolutionary field, NT will stimulate and accelerate integration among a variety of expertise to provide promising outcomes in the near future.

The Authors' Contributions to R&D in ChE, PT and NT

W.T. was aiming for a Colombo Plan scholarship when he was persuaded by his friends to sit for the then obscure Japanese Monbusho Scholarship Exam. As the last stand-by candidate, he obtained a scholarship after three persons declined it. At the suggestion of a Thai senior majoring in Industrial Chemistry in the University of Tokyo, W.T. decided to switch his major from the highly popular electrical engineering to chemical engineering. He foresaw that Thailand could not do without ChE if it was to industrialize with heavy chemical industries. In 1969 a year-long student strike forced the 1st-ranked University of Tokyo to cancel its entrance exam, thereby automatically resolving W.T.'s dilemma of living in a huge metropolis, so he entered the 2nd-ranked Kyoto University.

Although he was born into a rich banker family, the bank went bankrupt when he was still a few years old. When he was in middle school, his father wanted his sons to gain practical experience by beginning work immediately after finishing middle school. Fortunately, his divorced mother did all she could to support his desire to go to high school and university. Naturally W.T. never dreamed of studying in Japan, not to mention even in the USA.

During his senior year he met one of his ChE professors who *unexpectedly* offered to secure him a Research Assistantship at the University of Texas at Austin, provided he could pass the TOEFL requirement and study for a PhD, not a Master degree. Thanks to his previous English preparation for the Colombo Scholarship, W.T. managed to obtain a TOEFL score of 660 at his first try with just one-month of preparation. At UT Austin, W.T. did his doctoral dissertation in computer simulation of a stochastic process. Joining CU right after graduation with his conviction, obtained in Japan, of the *utmost importance of human resources development*, W.T. decided to do more practical research with a suitable proportion of experimental work. In response to the oil crisis of the 1970s, W.T. pioneered research in heat pipe technology and focused on energy conservation technology and process optimization. Subsequently the co-author T.C. joined a research team under W.T. to develop a novel wickless closed-loop heat pipe exchanger which could convey an axial heat flux of more than 464 watts[5]. After heat pipe technology became well accepted and rather mature, W.T. decided to "leave this field" upon successful completion of a pilot-scale demonstration project supported by National Research Council of Thailand (NRCT).

In the meantime, in response to the national project on natural gas exploration and utilization, W.T. helped prepare and push for the opening of an undergraduate petrochemical engineering option in the ChE Dept. of CU, as well as Thailand's first-ever Doctoral Program in ChE. At that time the conventional wisdom was that Thais should study for their Ph.D. abroad. W.T. strongly believed that *the research capacity of Thai universities and professional HRD could not effectively be upgraded as long as Thailand did not have her own domestic Ph.D. programs*. W.T. also proposed and succeeded in having NRCT and the Japan Society for the Promotion of Science (JSPS) create a Petrochemical Engineering Research Cooperation Program between Thailand and Japan. In fact, he served as its Thai-side program leader for 10 years, during which he also embarked on research in petrochemical reaction engineering (synthesis of methanol and ethanol from syngas, hydrodesulfurization of hydrocarbons, etc.) and taught several courses in petroleum refinery, catalytic reaction engineering, and petrochemical process industry.

Along with catalyst preparation involving powder handling technology, W.T. also continued to work on aerosol engineering (air pollution control), drying technology etc., which he initiated soon after joining CU. While Dr. Piyasan Prasertdham was setting up a Catalyst Engineering Lab in the ChE Dept. and CU was

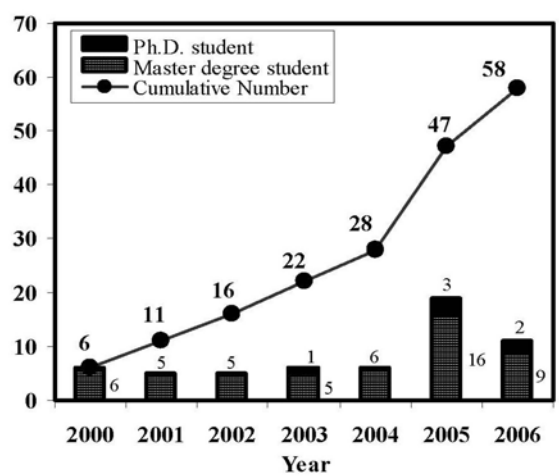

Fig 1. Cumulative and numbers of human resources produced from CEPT.

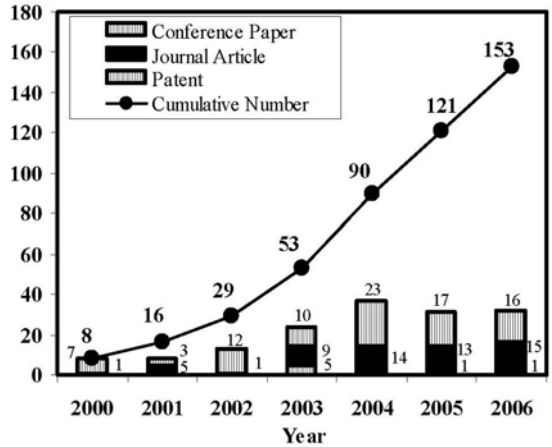

Fig 2. Cumulative and annual numbers of academic outcomes of CEPT.

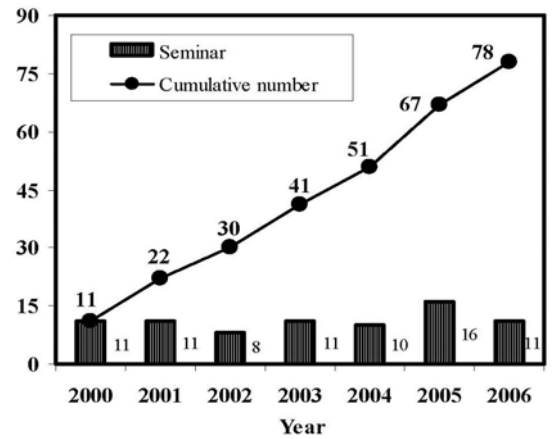

Fig 3. Cumulative and annual numbers of technical seminars organized by CEPT.

busy establishing a Petrochemical and Petroleum Technology College, W.T. was asked by his Japanese acquaintances in SPTJ and APPIE about the establishment of TPTC in CU in 1993. Around the same time, upon graduation from University of Tokyo, T.C. made up his mind to join the ChE Dept. and participate in TPTC activities. With a background in fluidization technology, T.C. has contributed to particulate granulation and coating as well as other relevant operations, such as particle characterization, dust collection and dust explosion. As shown in Figures 1-3, since 2000, CEPT has organized 78 public and in-house seminars and produced 58 graduates from Bachelor to Doctoral levels, together with publications of about 150 articles and 7 patents[6]. These graduates are now making contributions in numerous prominent industrial and academic organizations inside and outside Thailand.

In 2003, W.T. and a delegation from NSTDA were invited by JICA to visit Nanotech 2003 and Exhibition in Japan. Unexpectedly, W.T. (nanomaterials, Asia) was suddenly asked to be a panelist alongside a 1998 Physics Nobel Laureate Dr. Horst L. Stormer (nanoelectronics, America) and a Director-General from France's Commission of Atomic Energy (CEA LETI) (nanobiotechnology, Europe) to give advice to top young Japanese researchers on what and how to do NT research. The plenary panel was attended by over 400 participants from all corners of the world. Dr. Stormer's advice can be summed up as 4 L's (Learn, Love, Link, and Leave). Speaking first, W.T. recommended: Curiosity, Passion, Analogy, and Serendipity. Surprisingly, the first 3 neatly coincided with Dr. Stormer's Learn (be curious, never stop learning), Love (have passion in the research we are doing), and Link (use analogy across subjects, disciplines). By the way, the 4th L (leave) is the courage to leave one's comfortable nest to seek exposure to new environment / work circumstances as well as to doubt the existing dogmas.

In short, from the past to the present, changes have taken place endlessly in our society as well as the authors' lives. Our S&T-based society shall also follow the same rule. Both PT and NT have separately undergone and will undergo various stages of development. Recently, numerous researchers are interested in tracing nanoparticles and their derivatives. Such endeavor requires clever intensive scientific investigation. As researchers, we must not be afraid of changes and should always be ready to tackle any scientific and technological challenges using our strong fundamental background in S&T. With only limited resources, Thailand should make use of her human connection/ network as a vital factor for success in bettering the living standards of her people.

Concluding Remarks

Chemical Engineering was born out of the necessity to serve the chemical process industries. Recently ChE has diversified into newly emerging fields such as Nanotechnology and Biomedical Engineering. Meanwhile, Powder/particle technology offers very useful multi-disciplinary expertise, which has made distinctive contributions to the high-tech industries, thereby providing effective production of particulate materials which are essential building blocks of countless products used in the downstream industries and our daily life. A logical extension of PT, nanoparticles and to a certain extent Nanotechnology have successfully aroused researchers in diverse fields to collaborate and share their advanced knowledge, experiences and facilities with the ultimate goal of bettering the living standard of our people and

prosperity of mankind.

The authors are fortunate to directly experience the joys and excitement of Chemical Engineering through Powder Technology to Nanoparticle Technology. Our words of advice to the next generation are as follows:

- Be fully prepared: Uncertainty is the most certain thing in life.
- Practice the 4 L's of Love, Learn, Link and Leave.
- Success depends on 10% inspiration and 90% perspiration.
- Don't be afraid of failure and don't play the blame game: take it as lesson learned.
- We only live once: leave a proud legacy (perhaps this may be the 5th L).

Since W.T. joined NANOTEC, he has had to confront the reality of academic pursuit vs. real-world applied research. Two additional recommendations are:

- Begin with the end in mind (one of the 7 habits of most effective leadership) when initiating a research project.
- In addition to the popular "inside out" approach in selecting a research topic, try more the "outside in or customer-focused" approach when doing applied research.

Acknowledgement

Support from Chulalongkorn University to CEPT and Siriporn Monchayapisut's help in preparing Figures 1-3 are acknowledged.

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