Technology innovation and its impact on sustainable development

A case study of China

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Abstract

The deepening of the reforms and opening-up of China in the early 1980s witnessed a rapid increase of market economy and rise of environmental pollution. Water pollution from Beijing Brewery was one case in environmental dispute. Researchers from Tsinghua University were requested to develop Upflow Anaerobic Sludge Blanket (UASB), an environmental technology for water treatment to help Beijing Brewery deal with the problem under local conditions in China. Based on sharing of global knowledge, UASB brought significant technological and institutional innovations to beer industry, successfully improved sustainability of this industry, and ensured its further development. It is a typical example of how science, technology and innovation help implement sustainable development goal in contemporary history.

Introduction

With the deepening of the reforms and opening-up of China in the early 1980s, China's enterprises found themselves in the midst of a rapid increase of commercial economy calling for large amount of consumer goods. They began to introduce advanced technologies from developed countries to increase their production capacity. These introductions not only satisfied the demand of productivity growth in a short time, but also brought about severe and widespread social problems. One of these was environmental pollution. This article talks about environmental problems triggered by the discharge of high concentration organic wastewater from Beijing Brewery, a famous brewery in Beijing at that time, and explores how research team from Department of Environmental Engineering at Tsinghua University developed UASB[1] technology to solve the problem of responding to the request of Beijing Brewery. What is more, the successful innovation of UASB made this technology a significant element integrated into China's beer industry, which supported sustainable development of the industry. This can be seen as a typical example of how science, technology and innovation play a major role in the implementation of sustainable development in China.

The origin of environmental problem

In 1980, China's central government declared a long-term plan of economic development. According to this plan, China would double its gross national product within next ten years, and double again in the following decade before new century. Economic development became a main issue in China's society. The process of urbanization and industrialization began to accelerate accompanied by the rising of residents' purchasing power and demand for commodities. Per capita income in Beijing increased at an annual growth rate of 10% from 1978 to 1985, which created an expanding market of light industrial products like beer, foodstuffs and textile. In order to occupy the beer market and keep competitive, Beijing Brewery carried out a project of extending beer production lines. After a wide survey of beer industry in Western Europe around 1981, Beijing Brewery introduced a series of western technologies such as beverage-packaging production line from Germany and brewing technique from Denmark, which greatly shortened production cycle and increased production capacity.

In 1985, Beijing Brewery produced 56,000 tons of beer compared with 20,000 tons in 1980. When planning the next phase of production capacity extension, they had to stop and turn around to deal with the by-product of production capacity extension in the first phrase: a high discharge of high concentration organic wastewater from their production lines equipped with newly introduced techniques. Due to carelessness in addressing the environmental problems and lack of investment in pollution disposal device, over 1000 tons[2] of organic pollution was discharged into the river without treatment in a single year. To make matters worse, after years of urbanization and industrialization, what used to be farmlands down the river had become residential area and industrial area with a higher density of population.

Water pollution made Beijing Brewery and other beer enterprises main targets of environmental dispute in Beijing. They were criticized for being contributors of water environment degeneration as well as threat of drinking water and fishery

[1]Upflow Anaerobic Sludge Blanket, a typical method of organic polluted water treatment using anaerobic biochemical reaction of microorganism.

[2]It was measured by the method of Chemical Oxygen Demand (COD), which uses strong oxidants to simulate complete degradation consuming oxygen. The consumption of oxidants is converted into the mass of oxygen with the equivalent effect. This mean shows how much oxygen is needed when organic pollutant completely degrades into water and carbon dioxide.

industry. At that time, over 100,000 tons of organic pollution was discharged into the water body of Beijing area, more than half of which was from industrial production especially from light industries. There was no more environmental capacity for pollution from extra production. This problem was added to the intense situation of water resource shortage triggered by more population and industries in Beijing. Enterprises were faced with a high pollution fine and threat of closing production lines from Beijing local government. What they had developed in turn restricted their long-term development. Economic achievement of Beijing area was also in the danger of environmental disaster. Obviously, specific environmental technology should be integrated into the system of beer industry to help enterprises get rid of this dilemma. But for a premature industry in China, none of these beer producers had the resources to develop environmental technology to solve the problem on their own. They were compelled to seek support from outside the industry.

The starting point of UASB technology development

Water pollution problems rising from the development of China's industry had been well concerned by China's researchers of environmental technology from the late 1970s. The disposal capacity of urban domestic sewage treatment plants were based on traditional aerobic activated sludge process,[3] and unable to catch up with the increase of discharge of water pollution as the number and scale of industries increase at a high speed. Municipal sewage system had yet covered two-thirds of Beijing area even in the early 1980s. Beyond that, rapid development of industries brought about a shortage of energy supplies, which consequently caused higher energy price and more cost for water pollution treatment using traditional method. China's researchers of environmental technology realized that new technology with higher disposal capacity and lower energy cost was crucial for the solution of high concentration organic wastewater. And this technology should be operating inside industries so as to undertake the due obligations of pollution producers, at least lightened the load of municipal system. However, environmental technology in China was just a newly developing field at that time. Resources for researchers were limited as well. The good news was that after the reforms and opening-up of China, academic communication at home and abroad had become normal. China's researchers were able to contact with their foreign colleagues in developed countries. Stimulated by environmental movement from the 1960s and 1973 oil crisis, anaerobic bioreactors[4] became hot in water pollution treatment around the world especially in Western Europe. Because this kind of technology had the potential of dealing with high concentration organic wastewater with lower cost of energy and even reproducing methane to recycle energy. Therefore, anaerobic bioreactors were thought to be ideal technologies for the treatment of high concentration organic wastewater. Low rate of sludge production (potential cause of secondary pollution) was also added to its environmental friendly characters. One typical technology of this kind was UASB invented and developed[5] since 1971 by Prof. Gatze Lettinga and his team in Wageningen University, The Netherlands, based on the discovery of anaerobic granule sludge. UASB had been successfully applied in some Western European countries from 1978 and telling a good prospect of development. What could not be overemphasized is that Prof. Lettinga declared the fundamental principles of UASB would be always open to other researchers especially to ones from developing countries. This information greatly encouraged China's researchers devoted themselves to the development and promotion of UASB technology.

Although the fundamental principles and other information about application experiences were already accessible, there was still a long march before UASB technology became applied in China because of lack of investment and research conditions. Beijing Institute of Environment Engineering carried out a productive experiment of UASB in 1981.The performance was a little disappointing and far from being practical. The reasons were unawareness of some technical details and failure of representing appropriate conditions that could be easily realized in laboratory but hardly at a bigger scale. In fact, application of UASB in Western Europe in the 1980s overcame these difficulties mainly by accumulating experiences when reactors were tested and adjusted in productive experiment, in which middle or full scale of reactors were dealing with real pollutants and operated inside the factory. Some experiences were even unique in specific environment for specific kind of wastewater. When researchers from Department of Environmental Engineering, Tsinghua University, were sponsored by central government to solve these difficulties in 1983, they realized that they had to prepare a research environment approximating the working condition of China's factory, such as a working station inside factory and supported by the enterprise, as long as they wanted to put UASB technology into practice in China. In order to accomplish this mission, a group of water treatment researchers were organized as a special "anaerobic team", focusing their attention on UASB and similar anaerobic technologies. This anaerobic team quickly

[3]Aerobic activated sludge process is a traditional and widely used method of polluted water treatment using aerobic biochemical reaction of microorganism. It was invented in the 1910s. Its main weak points were (1) need quite a lot of energy to oxygenate the polluted water; (2) microorganism reproduce in a high speed creating surplus sludge with a related high rate needs further treatment.

[4]Anaerobic bioreactors make use of anaerobic biochemical reaction of microorganism turning organic pollutant into methane and carbon dioxide, but they were far from being perfect before the 1960s.

[5]UASB is based on the discovery of anaerobic granule sludge. Granule sludge was occasionally discovered when Prof. Lettinga was testing upflow anaerobic bioreactors. This granule sludge maintain a high population of microorganism and a density heavier than water, so as to keep a high level of biochemical activity when polluted water was input from the bottom with a relatively high quantity.

began to seek suitable site for technology development. As mentioned before, Beijing Brewery was seeking for technology support as well. Negotiation between University and enterprise did not take long. In 1984, Beijing Brewery made an official request that Tsinghua University should provide technology that helped solve high concentration organic wastewater problem in Beijing Brewery. And Beijing Brewery shall provide resources such as site and workers for anaerobic research team to build a working station of wastewater treatment engineering inside Beijing Brewery. Through this cooperation, anaerobic team got full access to the characteristics of wastewater and actual production situation of Beijing Brewery. They also obtained enough space and labor force for incoming pilot scale test and productive experiment. These conditions gave the research a smooth start.

Comparisons of design schemes

The anaerobic research team quickly proposed relevant schemes. In March 1985, they designed a system including a UASB reactor operated at medium temperature (around 35℃) and a submerged aeration biological filter[6] for further treatment. The design of medium-temperature UASB made use of experiences of similar medium temperature UASB in Western Europe and provided a relatively high removal rate for about 90% of organic matter when treating wastewater containing several thousands of milligrams of organic matter per liquid. It saved quite plenty of energy compared with high-temperature (around 55℃) UASB pursuing a high removal rate of 95%. In this system, medium-temperature UASB was specifically designed to dispose wastewater from saccharification process and fermentation process with a concentration of over 10,000 mg/L, making full use of UASB's adaptation to extra high concentration of organic wastewater. Anaerobic team successfully cultured and acquired ideal granule sludge that achieved a removal rate above 90% in laboratory. The remaining organic matter in the effluent of UASB reactor and lower-concentration wastewater from other processes of Beijing Brewery were left to submerged aeration biological filter. Simulated in laboratory, effluent concentration from submerged aeration biological filter was lower than 100 mg/L meeting the standard of sewage discharge in the condition that influent concentration was about 1,000 mg/L. When this system was compared with another scheme proposed also by Tsinghua University, in which two modified aerobic processes were series connected, the former system saved considerable amount of energy and produced equally considerable methane. The similarity of anaerobic process inside UASB reactor with that inside the fermentation process of beer production gave more convenience for workers and managers in Beijing Brewery to master the system. It seemed hopeful that proper controls of temperature, the situation of sludge, along with effective separations of water, sludge and gas might make medium-temperature UASB a practical process for wastewater treatment in Beijing Brewery.

But this system did not fully match considerations of Beijing Brewery, and performed several disadvantages:

(1) Uncertainty and cost of maintaining medium temperature: In order to maintain medium temperature, special devices and workers were needed. Considering the technological level and worker training of automation control in China at that time, it increased investment and operating cost of wastewater treatment as well as increased the risk of disfunction of UASB caused by failure of warm-keeping in full size reactor.

(2) Energy saving was not fully achieved: Submerged aeration biological filter, further treatment process in this system, was still an aerobic process that needed lots of energy for aeration. And warm-keeping for medium temperature was added to the total energy cost. Methane produced inside UASB reactor was unable to directly convert into energy that could be used in operating production line in Beijing Brewery or transported through power network. Moreover, it became a risk of fire and explosion if not properly collected.

(3) Complexity of the system: Using UASB for the specific treatment of wastewater from saccharification process and fermentation process led to adjustment of drainage system, which might cause interrupt of beer production. Also, two-process system required more workers and management increasing its uncertainty and cost compared with one-process system (if it was possible).

Considering practical requirements of the enterprise, obviously the potential of UASB reactor should be fully exploited. Anaerobic team found it inevitable to develop room temperature (around 20℃) UASB with high processing capacity if they wanted to solve this problem effectively and economically.

Technological innovation responding to enterprise's practical requirements

In the development of room-temperature UASB technology, two factors had tremendously changed outer social environment and put the development of this technology forward. The first factor was central government's special funding for anaerobic technologies. A special program named "Anaerobic Biological Treatment Technologies of High Concentration Organic Wastewater" was established and funded by central government in the framework of National science and technology research plan in 1986. This program, aiming for practical environmental technology requirement from a few of China's developing industries like beer and subsidiary foodstuff, provided considerable funding and other resources for technological innovation of anaerobic technologies. Anaerobic team and Beijing Brewery cooperated to apply for this program and succeeded. Through the platform serving the national research plan, they got more access to funds from central government and information about new achievement

[6] An aerobic modified process in which exchange efficiency of oxygen is reinforced and filtration of biological membrane is utilized.

of UASB inside and outside the country. For instance, Prof. Lettinga was invited to China several times in the form of assessment expert of this program, and several special teams were organized to study new application of anaerobic technologies in developed countries by on-site visit and make public reports to the whole team of program. The development of room-temperature UASB technology benefited a lot from these exchanges of information. The second factor was adjustment of municipal drainage planning. From 1985 to 1986, the environmental protection research institute of Beijing carried out a program named "Study on Technological Policy of Water Pollution Prevention and Control in China". This task, raised by State Environmental Protection Administration[7], required a systematic solution of water pollution control under specific situations of available technologies and limited investment in China. This study showed that by using municipal sewage plants dispose wastewater that had been properly preprocessed and collected from industries, total investment (public investment and enterprise investment together) would be 25% off and operating expense would be 50% off compared with those when water treatment was done entirely and separately by enterprises. According to early result of this study on the situation in Beijing area, Beijing local government adjusted local sewage discharge standard in October 1985, allowing enterprises discharge wastewater under a concentration of 500 mg/L organic matter into municipal sewage plants and requiring reasonable fee for disposal of the rest of organic matter. This adjustment meant it was possible that developed room-temperature UASB as a one-process system might fully accomplish the task of wastewater treatment apportioned to Beijing Brewery.

Driven by these factors, anaerobic team made two breakthroughs in development of room-temperature UASB.

(1) Successful cultivation and acclimation of granule sludge at room temperature: Based on experience at medium temperature, researchers used methods to investigate the relationship between processing capacity and physicochemical/biochemical characters of granule sludge. After necessary preprocess like filtration of big particle, adjustment of acidity, and controls of operation parameters, they acquired stable granule sludge with enough microbial activity at room temperature.

(2) Optimal design of UASB reactor: Great effect was also made to maximize separations of water, sludge and methane. Effective separations would help maintain granule sludge in good condition with high density of microorganism and decrease organic matter carried by effluent. Separator initially designed as combination of several bigger devices was split into dozens of smaller units, which greatly reduced the possibility of "dead zone"[8] and improved separations. Unitized design provided convenience of construction and transport of reactor as well. When it came to other supporting devices such as methane utilization and automatic control, they had to use technologies at hands to realize a relatively satisfactory result. Take methane for example, it was collected and stored in a specific tank and then burnt in kitchen for cooking or in boiler room for hot water. This kind of recycle of energy could also be very satisfying and safe.

These breakthroughs paved the way for pilot scale test of room-temperature UASB technology. The first pilot scale test of room-temperature UASB technology in China was successfully completed in Beijing Brewery at the end of 1988. In this test the potential of room-temperature UASB was fully exploited. Statistics showed a removal rate of over 85% when UASB reactor disposed mixed wastewater from all the processes of production lines and living quarter with a concentration of 2,000–3,000 mg/L, fulfilling the request of effluent concentration below 500 mg/L in one process. This performance was even better than plenty of medium-temperature and high-temperature UASB reactors in operation around the world at that time. Its operation was simplified to its best and needed no more further process in Beijing Brewery. It reduced energy cost and recycled considerable amount of methane. Supported by succeeding funding from central government and necessary resources from Beijing Brewery, the construction of the biggest practical UASB reactor in China at that time was completed in Beijing Brewery in November 1991. Based on design in pilot scale test, the reactor was designed as eight parallel units that could be operated separately providing flexibility for wastewater treatment and reducing the complexity of management. The whole reactor had a volume of 2,000 m^3 and a capacity of dealing with over 2,600 m^3 of wastewater at room temperature each day. Its removal rate was over 80%, and fulfilling the request of effluent concentration below 500 mg/L. If a reactor used traditional aerobic technology with similar capacity, it might take more than twice its volume and occupation of land. According to economic calculation of UASB reactor during trial operation in 1992, Beijing Brewery paid only 0.09 yuan RMB for electricity to deal with one cubic meter of wastewater in this reactor. Even not taking the benefit of methane recycle into account, the total cost for one cubic meter of wastewater was 0.48 yuan RMB, far lower than the price of over-standard discharge into municipal sewage system causing extra fee from sewage plant and high fines from government. The investment of construction was controlled at a reasonable level, too. In the long run, as mentioned in the reports of anaerobic team about room-temperature UASB technology at the second half of the 1990s, it saved 15–30% of construction investment and 30–50% of operation cost compared with traditional aerobic technology.

In 1993, Beijing Brewery had an increase of beer production by 11% over the last year, but still reduced organic matter discharge for 357 tons, adding to the reduction of about 500 tons in 1992 when the period of trial operation was included. The construction of UASB reactor guaran-

[7]Its function was nearly the same as that of US Environment Protection Agency (EPA) in United State.
[8]Bigger devices easily create zones where flow becomes slow or even static leading to failure of devices.

teed the production extension plan for 120,000 tons of beer per year, and the whole Beijing Brewery realized a profit of 3,789,000 yuan RMB in 1993, indicating a good future of Beijing Brewery supported by UASB technology.

Institutional innovation to sustainable development

Through the cooperation with Tsinghua University, Beijing Brewery was able to apply and share the achievements of technological innovation of UASB. Technology strength for UASB was developed in Beijing Brewery, too. More importantly, under the help of anaerobic team, a stable management system was established, which adapted to UASB and integrated UASB into the whole technology system of beer production. This integration started at the very beginning of cooperation, when workers and managers from Beijing Brewery were engaged in research and development activities. In the process of UASB development, members from enterprise were able to form personal cognition of environmental technology that was unlike other technologies used in production activities. Under the help of anaerobic team, these members became familiar with UASB technology and translated requirements, parameters, and responsibilities of every position concerning UASB reactor into language that was generally accepted in production system of Beijing Brewery. The translation was fixed in the form of "Sewage treatment station rules and regulations" establishing a special workshop and shift system for wastewater treatment. All of these were integrated as a part of the enterprise's management system. This institutional innovation proved its value as soon as anaerobic team completed their research and moved out from Beijing Brewery.

Beijing Brewery smoothly took over all the jobs of UASB operation even before the researchers left and kept the reactor in sound condition for long run. This institutional innovation also made Beijing Brewery an outstanding example of sustainable development in beer industry. It drove the spread and application of UASB in beer industry and in turn reshaped outer environment to a favorable one for the development of Beijing Brewery.

Being praised and reported by government, Beijing Brewery was frequently consulted and visited by other enterprises in beer or even other industry faced with similar environmental problems. Visitors were shocked by the fact that dirty polluted water could produce clean energy for recycle in Beijing Brewery, especially its clean dining room opened to the public using methane produced by UASB reactor. More significantly, Beijing Brewery was glad to share its practical experiences on operating UASB reactor and how to integrate it into the whole system of enterprise. These valuable experiences cooperated with supporting policies from government, they were two important factors for the promotion of UASB. They worked together to persuade a few enterprises to introduce UASB technology into their factories. It became a nationwide mode of spread of UASB technology in beer and other industries in China, and Beijing Brewery even received profit from technology transfer for being a holder of UASB technology. The successful spread of UASB technology in China had even created a market for granule sludge[9]. By stable operation of UASB reactor ahead, Beijing Brewery was able to provide considerable amount of granule sludge at a price of no less than 200 US dollars per cubic meter of sludge. The price was more than twice in some years, but the supplies even could not meet the great need for new reactors in the 1990s. It became another profit for being the first one of UASB technology user and contributed to the development of UASB in China.

Supported by UASB and other anaerobic technologies, beer industry in Beijing area made a smooth development. The total production of beer in Beijing area raised to 1,170,000 tons in 1998 compared with 135,000 tons in 1985, and the whole industry realized considerable discharge reduction at the same time. It happened in other areas of China as well. For instance, Tsingtao Brewery, mother of world famous Tsingtao Brewery Company Limited, introduced UASB technology from Tsinghua University and Beijing Brewery in the mid-1990s. The introduction solved water pollution in a short time and UASB technology was integrated into the system of Tsingtao Brewery. In the expansion of Tsingtao Brewery Company Limited, using technology to control pollution was always well concerned no matter building new factory or taking over other enterprises are concerned. According to incomplete statistics in 1999, 219 anaerobic reactors were used in China's industries and over 120 of them were UASB reactors. UASB technology had become the mainstream technology of wastewater treatment in beer industry and starch industry in China. Success of UASB technology in China also attracted attention from abroad. Around 1995, anaerobic team provided two wastewater treatment design schemes to a French beer enterprise, in which UASB reactor was a key component. In December 1996, Department of Environmental Engineering, Tsinghua University, signed a cooperate contract with Kankyo Engineering Co. Ltd., Tokyo, Japan, for "UASB technologies' transfer". Achievement of UASB technology in China was also fully affirmed by Prof. Lettinga, the original inventor of UASB, in several occasions.

What UASB brought to beer industry was not merely technological or institutional innovation, but also improvement of industry image and change of view for development. Beijing Brewery is an example. Being the first in China applying UASB technology, Beijing Brewery became a demonstration enterprise of green production in the early 1990s attracting visitors from different social organizations, industries, and government at home and even abroad. It was a free and an effective broadcast for Beijing Brewery and its products. The image of troublesome polluter in

[9]To operate a UASB reactor at full load, at least one-third of volume of reactor should be prepared with granule sludge in good condition. If not transferred from other sources, it would take mouths for cultivation and acclimation of granule sludge. No mention of the risk of failure.

citizens' minds was taken place by an environment-friendly and well-accepted beer producer. Being an outstanding example of green production, Beijing Brewery was also introduced by Beijing local government to apply for Environmental Technical Assistance Program of World Bank in 1993. This application was accepted in the framework of Clean Production subproject (B-4). It reinforced technology and management system for clean production in Beijing Brewery, and strengthened the idea of sustainable development in enterprise culture. The innovation of UASB technology was a penetration point of bringing idea of sustainable development into China's beer industry. It pushed the development of the whole industry to a more sustainable direction.

Conclusions

The achievement of UASB technology in China's beer industry can be attributed to three factors: (1) sharing of knowledge about UASB technology among environmental technology researchers all around the world; (2) great effects made by China's environmental technology researchers, including anaerobic team, to technological innovation focused on local conditions and requirements in China; and (3) active involvement of enterprises and government's support especially in institutional innovation. The innovation of UASB technology along with other environmental technologies turned China's beer industry from an extensive mode to a sustainable mode in the early 1990s. The case of Beijing Brewery more than 20 years ago makes it clear that enterprises' involvement in science and technology innovation is indeed an important way for enterprises to accomplish new development in a global atmosphere of environment concerned. It is equally clear that supporting science and technology innovation is a practical way for government to promote sustainable development in society and implement sustainable development goal.

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Climate Technology Centre and Network

The CTCN is the operational arm of the UNFCCC Technology Mechanism, hosted by the UN Environment Programme (UNEP) and the UN Industrial Development Organization (UNIDO). The Centre promotes the accelerated transfer of environmentally sound technologies for low carbon and climate resilient development at the request of developing countries. CTCN provides technology solutions, capacity building and advice on policy, legal and regulatory frameworks tailored to the needs of individual countries.

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