DOI 10.15302/J-SSCAE-2019.02.014

Construction of Safe, Reliable, Clean, and Environment-Friendly Refining and Chemical Enterprises

Zhang Shucai[1], Zhang Xiaohua[1], Jia Ping[2], Wang Qian[3], Cao Xianghong[4]

1. SINOPEC Qingdao Research Institute of Safety Engineering, Qingdao 266100, Shandong, China
2. SINOPEC Luoyang Engineering Co., Ltd., Luoyang 471003, Henan, China
3. SINOPEC Engineering Incorporation, Beijing 100101, China
4. China Petroleum & Chemical Corporation, Beijing 100728, China

Abstract: In China**,** refining and chemical enterprises in urban and other densely populated areas are facing significant pressure to relocate or upgrade. To solve this problem, surveys were conducted on the overseas refinery industry to learn from their advanced security management experience. The principles, performance indicators, and evaluation methods for safe, reliable, clean, and environment-friendly refining and chemical enterprises were then defined. It is suggested that construction of such enterprises would be an effective way to solve the aforementioned problem. Furthermore, two case studies were conducted, and the feasibility of this method was proved. Departments concerned should adopt scientific methods to calculate the distance between enterprises and urban areas, and continually abide by this to avoid the phenomenon of petrochemical enterprises being surrounded by urban areas. Moreover, different schemes should be carefully examined and scientifically evaluated before deciding whether the refining and chemical enterprises in densely populated areas should be relocated or transformed in-situ.
Keywords: safe and reliable; clean; environment-friendly; oil refining; chemical industry; external distance

1 Introduction

China's fast-growing oil refining and chemical industry has become an important industry in the national economy, ranking second globally in terms of oil refining and ethylene capacities and first in terms of production of aromatics, three major synthetic materials (plastics, synthetic fibers, and rubber), and modern coal chemical industry [1,2]. With the development of urbanization, according to available statistics, there were 27 473 oil refining and chemical enterprises above designated size in China by the end of 2016. However, without strict planning and control in the process of urbanization, most of these enterprises are located in densely populated areas along rivers, coasts, and highways, which have posed threats to social stability, and the life and property of surrounding residents. Specifically, in the past decade, accidents have frequently occurred in China's oil refining and chemical industry, such as the Jiaozhou Bay oil spill accident caused by the Huangdao pipeline explosion in 2013, the Lanzhou CNPC water contamination event and Tengger desert pollution discharge event in 2014, and the fire at Shandong Linyi Jinyu Petrochemical Co., Ltd. caused by an explosion in 2017. These accidents have aroused widespread concern and "fear of petrochemical constructions." From 2007 to 2014, mass protests against the construction of paraxylene chemical (PX) projects occurred successively in Xiamen, Zhenhai, Chengdu, Kunming, and other locations.

Received date: December 15, 2018; **Revised date:** February 15, 2019
Corresponding author: Cong Bin, Zhang Shucai, senior engineer of SINOPEC Qingdao Research Institute of Safety Engineering. Major research field is HSE management of energy and chemical industry. E-mail: zhangsc.qday@sinopec.com
Funding program: CAE Advisory Project "Construction of Safe, Reliable, Clean and Environment-Friendly Oil Refining and Chemical Enterprises" (2016-XZ-08)
Chinese version: Strategic Study of CAE 2019, 21 (2): 111–116
Cited item: Zhang Shucai et al. Construction of Safe, Reliable, Clean, and Environment-Friendly Refining and Chemical Enterprises. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2019.02.014

To systematically prevent major fires and explosions, eradicate major pollution accidents that disturb people or the ecological environment, and maintain social stability, the General Office of the State Council set forth the requirement of promoting the relocation and reconstruction of chemical enterprises in densely populated urban areas in the *Guiding Opinions on Advancing the Relocation and Improvement of Hazardous Chemical Manufacturers in Populous Urban Areas*. This was released in 2017 and put enormous survival pressure on the oil refining and chemical industry. The conflict between urbanization and industrial development is a universal problem, and relocation is not the sole solution. Some fundamental measures to ensure the harmonious mutual development of industries and cities in China include learning from developed countries' practical experience; sticking to facts-based truth-seeking and scientific analysis; improving safety and environmental protection technology and management of oil refining and chemical enterprises; building safe, reliable, clean, and environment-friendly refining and chemical enterprises; and adopting differentiation strategies.

2 Developed countries' practical experience

2.1 Harmonious mutual development of refining and chemical enterprises and cities

A field investigation into refining and chemical enterprises in Germany, Japan, and other developed countries reveals they have achieved good safety and environment-friendly performance by adopting advanced technologies and management measures, and readily accepting the oversight of surrounding communities, thus realizing the harmonious coexistence between enterprises and cities.

Founded by Badische Anilin und Soda Fabrik (BASF) in 1866, Ludwigshafen Chemical Industrial Park has become a large-scale petrochemical complex with more than 200 sets of production facilities, covering an area of 10 km^2, with an annual production and sales volume of 8.5×10^6 t. As it adjoins the Rhine, materials and products are transported in and out of the industrial park by ships; 350 000 employees work in the park, and more than 2 000 transport vehicles enter and leave the park every day via the 106 km highway and 230 km railway. Located next to Mannheim, the park is built on the bank of the Rhine, the mother river of Europe, facing residential quarters across a road (Fig. 1), a layout that displays a typical "urban" chemical industrial park.

Similarly, Japan's 70-year-old Negishi Refinery is only separated from the surrounding residential areas by a 2-lane road (Fig. 2). The refinery is safe, reliable, clean, and environment-friendly, allowing it to operate in harmony with the local community.

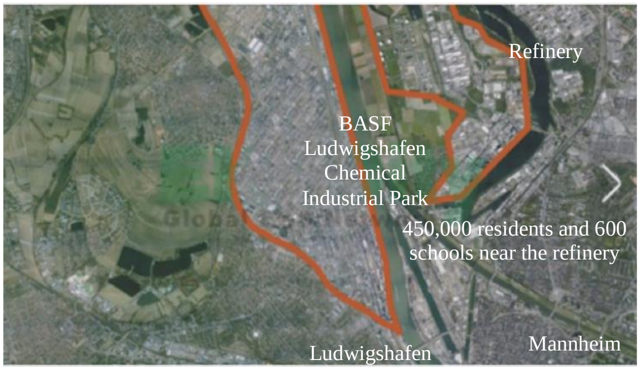

Fig. 1. Aerial view of BASF Ludwigshafen chemical industrial park.

Fig. 2. Distance between Japanese Negishi Refinery and the community.

DOI 10.15302/J-SSCAE-2019.02.014

2.2 Determining the external distance of the enterprise according to the evaluation results

Countries around the world have many ways to determine the safe distance between oil refining and chemical enterprises, and other urban functional areas. There are three common methods: the first is to enforce a conservative numerical requirement for safe distance uniformly without considering accident differences, which is called the universal distance method. The second method is based on accident consequences, namely, "the worst case scenario," which assumes the area affected by fire, explosion, poisoning, and other accidents. The probability of all accidents is reduced to determine the distance and the results usually indicate a rather long safe distance; this method is relatively conservative. The third is to consider the probability and factors such as intercoupling relationships among various accidents and the reliability of protective measures, which is usually a rather short safe distance. This method is more consistent with the actual situation, but requires a complicated calculation process. The application of these three methods in developed countries is presented in Table 1 [3,4].

As shown in Table 1, the universal distance method is used less often in developed countries, while the evaluation technology based on consequences and risks is used more widely to determine safe distance. The trend leaves room for harmonious mutual development of oil refining and chemical enterprises and cities, and also effectively encourages enterprises to upgrade themselves in terms of safety and environmental protection.

Table 1. Safe distance determination methods adopted by foreign countries.

Country	Universal distance	Consequence-based	Risk based
The UK			√
The US		√	
Japan	√	√	
Belgium		√	√
France		√	√
Germany	√	√	
The Netherlands			√
Spain		√	
Switzerland		√	

Developed countries strictly enforce the safe distance of enterprises in the urban planning process. Take Tokyo as an example. Since its surrounding areas were divided into business, residential, and industrial zones at the end of the 19th century, the city has followed this pattern for more than 100 years [5]. On the one hand, the pattern ensures the long-term interests of the people; on the other hand, the scale of various functional zones around the city is effectively controlled, which avoids conflict between industrial development and other functional zones.

2.3 Classifying and handling the development issues of enterprises and cities based on risk evaluation results

In 2001, an explosion at a chemical plant in Toulouse, France, killed 31 people and injured more than 2 500. Learning from this, the French government introduced the Technological Risk Prevention Program (PPRT), which aims to solve historical problems related to enterprise and community security, and to provide decision-making support for urban development and land use planning.

The PPRT program involved 650 French chemical enterprises in rolling risk assessment, motivated extensive participation by local officials, enterprises, local residents, and associations, and evaluated all enterprise hazards and possible consequences. The results were quantitatively plotted on a map to divide regions according to different risk levels, and targeted measures were taken for each region at a certain risk level. For example, it is forbidden to build new houses in serious-risk regions, and existing houses must be demolished and relocated; protective measures (e.g., structural reinforcement, glass films) must be taken to protect buildings in relatively high-risk regions, parks are restricted from use, and assemblies are not allowed; people living in high-risk regions should be informed of unlivable conditions without compulsory demolition and removal, and residential construction in medium-risk regions should be controlled.

The PPRT program has attached equal importance to safety and environmental risk prevention, as well as future development, and its implementation has so far achieved good results and is therefore worth learning from.

3 Ideas and suggestions

Considering China's national conditions and foreign practices, the action plan for safe, reliable, clean, and environment-friendly refining and chemical enterprises should be promoted as soon as possible. The action plan has two implications: first, building the aforementioned oil refining and chemical enterprises is essential for solving the conflicts between development, and safety and the environment. Second, scientific risk assessment should be conducted for enterprises in sensitive areas, and whether an enterprise or a community should be relocated or reconstructed should be determined according to the risk assessment result. The action plan includes the following three parts.

3.1 Defining safe, reliable, clean, and environment-friendly refining and chemical enterprises and establishing an evaluation index system

Safety and reliability refers to the application of the system safety engineering principle, giving preference to intrinsically safe manufacturing techniques, promoting intrinsic safety of the process, and adopting scientific risk management methods and advanced technical measures to remove accident chains, eradicate all accidents at the serious level or above, enable individual enterprises to keep risk below 10^{-6}, and ensure social risks meet the national acceptable risk requirements. Cleanliness and environment protection refer to applying the environmental system engineering principle, combining source control with end treatment, prioritizing clean manufacturing techniques, making the process more environmentally friendly, adopting advanced treatment technologies and stringent management measures to eradicate environmental pollution and public nuisances at the serious level or above, and ensuring waste water, exhaust gas, and solid wastes (herein and after refers to as "three wastes") discharge surpasses national and local threshold standards.

Whether an enterprise is safe, reliable, clean, and environment-friendly cannot be simply evaluated by a single index. Instead, a systematic index system composed of multiple indexes should be considered. The index system of such refining and chemical enterprises includes three evaluation indexes: safety and reliability, cleanliness and environmental protection, and integrated management. In terms of safety and reliability, the indexes include the intrinsic safety of the process, the integrity and reliability of the equipment, and the stability of manufacturing and operations. Regarding cleanliness and environmental protection, we should consider the cleanliness of techniques, the development level of environmental protection technologies, and the discharge level of "three wastes." The integrated management assessment indexes should include management elements that affect the level of safety, reliability, cleanliness, and environmental protection, associating the results with the process, such as compliance evaluation [6], human resources and training, communication and participation, and contractor and supplier management.

After the index system of such refining and chemical enterprises is put forward, specific indexes should be designed according to system elements with corresponding weights assigned. Some examples of the index system framework are presented in Table 2.

Table 2. Systematic framework of indexes for safe, reliable, clean, and environment-friendly oil refining and chemical enterprises.

Type	Level-1 index	Index sample
Safe and reliable	Intrinsic safety of the process	Safety of the process, risk level of materials, reliability of the control scheme
	Equipment integrity and reliability	Finishing rate of equipment compliance, maintenance, and rate of equipment in good condition
	Stability of manufacturing and operation	Operational stability of process indexes, frequency of abnormal alarms
Clean and environment-friendly	Clean process and environmental protection	Environment protection level of materials and discharge load of "three wastes" in the process
	Development level of technology and operation performance of "three wastes" treatment devices	Resource utilization of wastewater, waste gas, and solid waste
	Separate discharge of "three wastes" and the qualified rate of total discharge	Pollutant load in discharged effluent and exhaust gas and the qualification rate

DOI 10.15302/J-SSCAE-2019.02.014

3.2 Improving the external distance evaluation method

3.2.1 Formulating and releasing new standards for the external safety protection distance of China's oil refining and chemical enterprises

Advanced safety distance determination methods should be acquired from foreign countries, taking the types and characteristics of refining and chemical enterprises into account and applying advanced technologies, such as the accident consequence and the quantitative risk calculation methods. It is recommended that the introduction of technical standards concerning the external safety protection distance, risk assessment, site selection, planning, and control of refining and chemical enterprises is sped up. In addition, a standard safety distance system should be constructed in line with international standards and China's national conditions, and the safety protection areas around refining and chemical enterprises should be defined and controlled in a scientific manner. In particular, we should learn from France in investigating enterprises that are close to residential areas and carry out risk assessment, taking measures such as enterprise transformation, resident relocation, housing reinforcement, and land planning adjustment according to the degree of risk.

3.2.2 Integrating atmospheric environment protection and health protection distance standards, and formulating new standards

The health protection distance and the atmospheric environment protection distance have essentially the same purpose, that is, to protect the health of people outside the factory. These two differ from each other in pollutant type and limit value, as well as calculation model selection, and both have shortcomings in these two aspects. As China has made progress in controlling the contamination caused by volatile organic compounds (VOCs) and poisonous and pernicious gases, this kind of pollution has been effectively controlled in the production process. Substantial changes have also taken place when pollutant discharge based on existing technologies and production process is compared with that at the time of previous standards.

The protection distance should be determined by applying the scientific calculation model. In this way, we can better protect people's health, simplify management procedures and costs, and guide and encourage enterprises to reduce unorganized pollution at sources in a better manner.

3.3 Making scientific decisions on the relocation of oil refining and chemical enterprises in sensitive areas

There are two options to solve the existing problems facing refining and chemical enterprises in China's densely populated urban and other sensitive areas. First, enterprises can implement systematic technical transformation for safety and environmental protection purposes according to the requirements of intrinsic safety and environmental protection. They can also comprehensively improve capabilities to manage and control safety and environmental risks, and transform themselves into safe, reliable, clean, and environment-friendly oil refining and chemical enterprises. At the same time, resident relocation and improvement of public facilities should be carried out within the influence range of the atmospheric environment to realize the harmonious coexistence of enterprises and cities. This option is known as an in-situ reconstruction scheme. The second option is the long-distance relocation of enterprises.

Instead of making simple uniform decisions, we should adhere to historical and dialectical materialism and make scientific decisions on the relocation of oil refining and chemical enterprises in sensitive areas. Decisions should be made on the basis of comparative studies on the economy, safety, and environmental protection of the long-distance relocation scheme and the in-situ reconstruction scheme.

4 Case study

Two typical domestic enterprises are selected for the case study. The specific idea is to first determine the index system, then collect the index levels [7] of 20 domestic and 5 international refining and chemical enterprises to derive the index rule from consecutive accident-free years, and finally refer to the world's most advanced safety and environmental protection indexes and integrated management practices to configure qualification indexes that can realize safety, reliability, intrinsic environmental protection, and harmonious coexistence with society. With such qualification indexes, investment amounts of a long-distance relocation scheme and an in-situ reconstruction scheme are calculated separately for case study enterprises to achieve the goal. In this way, we can obtain suggestions for decision-making.

4.1 Profile of enterprises

Enterprise A is a large oil refining and chemical complex in north China, equipped with 63 sets of production units and 68 sets of utilities and supporting facilities. The enterprise started site construction in the 1960s and after more than 50 years of development, it has an oil refining capacity of 1×10^7 t/a and an ethylene processing capacity of 8×10^5 t/a.

Enterprise B, located in the center of China's south market, has an evident geo-economic advantage and more than 50 sets of production units. Forty years after its establishment, the factory is now surrounded by communities. The enterprise has health protection distances of 1 200 meters and 500 meters in the oil refining and chemical industrial zones, respectively.

4.2 Implementation schemes

For enterprise A to improve itself, flow optimization is recommended, that is, a process integrating slurry reactor residue hydrotreating into solvent deasphalting, with products free from petroleum coke and petroleum asphalt. It decreases the sulfur content in the feed of two catalytic devices from 0.49% to 0.47% and from 0.55% to 0.40%, respectively, and reduces emission of flue gas pollutants. According to the external distance risk quantization assessment through quantitative risk assessment software, there are two villages as well as catering and entertainment venues (densely populated) within the 1×10^{-6} personal risk isoline influence range, which indicates relocation of these.

For enterprise B, the residue processing flow in the general process of crude oil processing from the original coking + solvent deasphalting process into the residual oil hydrogenation + coking + solvent deasphalting process is planned to be transformed. The 3# delayed coker is used to process the low sulfur vacuum residue of the 1#, with other vacuum residues added to residual oil for hydrogen desulfurization and solvent deasphalting. After the upgrade of equipment, a small village within the 1×10^{-6} personal risk envelope range has agreed to relocate after negotiation. On the basis of constructive measure improvement and overall plane optimization, the atmospheric environment protection distance is reduced to 50–200 meters.

Both enterprise A and B adopt integrated construction, management, and control, applying the process control system (PCS) at the process control layer, the manufacturing execution system (MES) at the manufacturing executive layer, the enterprise resource planning (ERP) at the production and management layer, and the enterprise application integration (EAI) at the decision-making management layer for hierarchical association control. Risk management technologies, such as reliability centered maintenance (RCM) based on flexible manufacturing cells, risk-based inspection (RBI), and reliability, availability, and maintainability (RAM) should be adopted to ensure intrinsic safety of equipment. An on-line corrosion detection system should be established for equipment and pipelines. An integrated plant safety monitoring system and emergency rescue rapid deployment kit (RDK) should be built. A safety data sheet (SDS) should be created, and hazard and operability (HAZOP) analysis and safety integrity level (SIL) analysis should be conducted on the basis of devices. Quantitative risk analysis (QRA) and RAM analysis should be conducted on the basis of factories, so as to perfect the risk assessment mechanism. The level of overall safety and environmental protection will be raised from four to seven, reaching the required degree of safety and reliability, and conforming to national and local environmental protection indexes.

4.3 Comparison of results

According to the current market price level, enterprise A needs to invest CNY 3.5 billion to meet the requirements of safety, reliability, cleanliness, and environmental protection. After the implementation, the average annual after-tax profit of the enterprise is CNY 227 million, and the payback period is 9.16 years (including a construction period of two years); enterprise B needs to invest CNY 4.3 billion. After the implementation, the annual average profit per ton of oil is CNY 472.97, and the after-tax payback period is 7.72 years. In this case, the optimization scheme is feasible.

According to the construction investment estimation for enterprise projects of similar scale, if the relocation plan is adopted, the investment (excluding tax) of each enterprise will exceed CNY 40 billion. Moreover, the construction of new utilities and supporting facilities for raw materials and products in and out of the factory will increase the potential risks, such as the logistics risk and cause waste of resources and occupation of new land.

5 Conclusions

China has a large number of hazardous chemical enterprises with a grim reality of logistics security and frequent

DOI 10.15302/J-SSCAE-2019.02.014

occurrence of safety and environmental accidents. Safe, reliable, clean, and environment-friendly refining and chemical enterprises prove to be a more economical and long-term option. The government should set the qualification standards for such enterprises by improving the evaluation index system. An action plan should be implemented in stages, scientific evaluation of the controversial enterprises should be conducted, and the investment and income for relocation and in-situ reconstruction should be comprehensively compared to make scientific and classified decisions. At the same time, we should enhance the authoritativeness of the risk assessment results, respect the external distance of enterprises in the land planning stage, and avoid the phenomenon of petrochemical enterprises being surrounded by urban areas.

References

[1] Luo H J, Lv X D, Zhao R, et al. 2016 review and 2017 outlook of global and China petrochemical industry [J]. International Petroleum Economics, 2017, 25(5): 51–60. Chinese.

[2] Fei H W, Chen R. Status quo of China's oil refining industry in 2017 and its outlook [J]. International Petroleum Economics, 2018, 26(5): 42–48. Chinese.

[3] Jiang X, Dang W Y, Wan G J. The safety protection distance analysis of urban refinery based on quantitative risk analysis [J]. Safety Health & Environment, 2017, 17(11): 14–17. Chinese.

[4] Ma G Y. Petrochemical plant payout based on explosion hazard source [J]. Petroleum Refinery Engineering, 2018, 48(2): 61–64. Chinese.

[5] Wang T. Change and enlightenment on spatial structure and planning for metropolitan area of Tokyo, Japan [J]. City, 2013 (10): 12–16. Chinese.

[6] Zhang S C, Jiang X Y, Li H. Theoretical method and application of environmental compliance evaluation for petroleum chemical enterprises [J]. Industrial Safety and Environmental Protection, 2013, 39(8): 74–76. Chinese.

[7] Zhang X H, He W. Contrast of HSE performance indicators and safety performance between domestic and international petroleum companies [J]. Safety Health & Environment, 2012, 12(2): 9–12. Chinese.