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ORIGINAL ARTICLE

Strategy of seawater utilization for tackling water shortage in Qingdao

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Abstract
The centralized water supply model is not suitable for desalinated water supply. The quality-specific water supply mode provides new ideas for water supply in seaside cities. Qingdao as a coastal city with abundant water resources, water supply complex design is first committed in Dongjiakou Economic Zone. The separate water supply system is applied in the Zone, the life and environment water supplied from municipal system, the industry process water comes from seawater and desalination water. The thermal power plant situates next the desalination plant, the seawater after used for cooling of the thermal power plant will be treated in desalination plant and used for industry process, as the purification water directly using in the industry process, the further treatment units will be not needed, the cost for the water advanced treatment in the industry will also be saved, and this is an example of circular economy.

Keywords Seawater · Desalination · Separate water supply · Chemical industry process

Introduction

The state of water resource shortage

Qingdao City is located in the southern part of Shandong Peninsula, with a total area of about 10,654 km^2, and the average temperature for many years is about 12 °C. The city's multi-year average precipitation is 688.2 mm (Cao et al. 2016) (equivalent to 7.33 billion m^3 of water), the annual average total water resources is 2.21 billion m^3, and the per capita water resource is 247 m^3, which is only 11% of the national average and 3% of the world level (Lu et al. 2019). Which is far below the world-recognized absolute water shortage standard of 500 m^3 per capita, and is one of the severely water-deficient cities in northern province of China (Zhang et al. 2015).

There are 224 rivers in Qingdao, most of which are seasonal rain source rivers. As shown in Table 1, the total water supply was 933 million m^3 in 2018, the local water source supply is 530 million m^3, and the cross-basin water diversion volume is 403 million m^3, accounting for 56.8% and 43.2% of the total water supply separately. The amount of sewage treatment and reuse is 43 million m^3, and the amount of seawater desalination is 25 million m^3, accounting for 4.6% and 2.7% of the total water supply; therefore, the cross-basin water transfer has become an important source of water resources in Qingdao (2019 Qingdao Statistic Yearbook 2019).

In 2018, residential water consumption, industrial water consumption, and farmland irrigation water consumption were 34.6%, 22.8%, and 20.9% of total water consumption; these are mainly used in Qingdao.

Condition of using seawater

Many regions in the water stressed countries are augmenting their water supplies with desalinated water to meet the needs of the continuous growth of population and industrial, tourism, and agriculture developments (Yangali-Quintanilla et al. 2015). Desalination has strong adaptability to raw seawater. The desalination rate of reverse osmosis technology is 99.8%, and most of the harmful substances can be removed. From the current technology, no matter what kind of desalination method can prevent pollutants from entering, the water quality would not be affected (Elsaid et al. 2020). Qingdao City has a special condition to develop the desalination industry. Qingdao is located on the coast of

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Table 1 The development and utilization of water resources in Qingdao in 2018 (unit: billion m^3)

Items		2018	%
Water supply	Local water resource		
	Surface water resource	2.21	49.5
	Ground water resource	2.41	
	Other water resources		
	Wastewater reuse	0.43	4.6
	Sea water desalination	0.25	2.7
	Cross-basin water diversion volume	4.03	43.2
	Total	9.33	
Water consumption	Farmland irrigation	1.95	20.9
	Planning and fishing water consumption	0.39	4.2
	Industry water consumption	2.13	22.8
	Urban public water consumption	1.001	10.7
	Residential water consumption	3.23	34.6
	Ecological environment water consumption	0.64	6.9
	Total	9.33	

the Yellow Sea, surrounded by Jiaozhou Bay, with a coastline of 730 km. There is no freezing in winter in Qingdao sea area. The seashore is dominated by sandy beaches and granite. The Qingdao's "three islands and one bay" urban layout presents a framework of a city along the coastline, and the industrial layout extends along the coastline. There are many coastal power plants, thermal power plants, and chemical plants. The conditions of co-generation of electricity and water facilitate the large-scale application of seawater desalination and provide a broad development space for the development of the desalination industry.

The development of seawater desalination in Qingdao can not only provides economical, safe, inexhaustible, and stable water sources, but it also is not affected by seasonal climate, increases the total amount of fresh water, and reduces dependence on cross-basin water diversion; the development of seawater desalination is conducive to environmental protection and land saving.

Case study on seawater and seawater desalination utilization plan in Dongjia Kou area

The current social non-differential water quality of the water supply cannot meet the different needs of urban water, and a single water supply system cannot achieve the rational allocation and utilization of water resources. The quality-specific water supply is an effective way to reasonably allocate and utilize urban water resources and to achieve "optimal use of water" (Li et al. 2005). It used water quality as a classification standard to rationalize the use of water resources and improve the efficiency of urban water use. The quality-specific water supply mode is mainly to set up a multi-pipe water supply system, using the potable water system as the main water supply system of the city, and set up other independent closed pipe network systems to transport non-drinking water such as recycled water and sea water as municipal water and industrial water, etc. (Lou 2016). Coastal cities have abundant seawater resources, and the seawater utilization industry should be vigorously promoted to solve the problem of urban water shortages. Seawater utilization includes direct seawater utilization and seawater desalination. According to statistics, the total industrial cooling water in coastal cities accounts for 50–70% of the total industrial water consumption. With the development of industrialization, the proportion of industrial water consumption will become higher. Table 2 shows the changes of industrial water in Huangdao District from 2014 to 2018, from which it can be seen that during the 5-years period (from 2014 to 2018), industrial water in Huangdao District increased by 8.28 million m^3, while the proportion of industrial water was as high as 37.1% by 2018. The results show the necessity of using seawater as industrial cooling water. If seawater is used to replace all industrial cooling water, more than 50% of the total urban fresh water consumption will be saved (Zhang 2013). To alleviate the current situation of water resources tension, Qingdao had built several desalination plants. However, due to the poor water quality stability and buffering capacity of desalinated water, it was difficult to guarantee the safety of water supply, and it had not been possible to carry out water supply on a large scale, so that the advantages of a seaside city near the sea cannot be fully exploited.

The Dongjiakou Economic Zone has the planned area of 284 square kilometers and three major sections: the port area, the industrial area, and the New port City. The Chemical Park of Dongjiakou Economic Zone is located in the

Table 2 Changes in industrial water use in Huangdao District from 2014 to 2018

Annual	2014	2015	2016	2017	2018
Industrial water consumption (million m^3)	4729	3992	4725	5260	5557
Percentage of total water consumption	28.6	36.0	28.7	32.5	37.1
Increase in volume over previous year (million m^3)	3	− 739	733	535	297
Annual growth rate (%)	–	− 18.5	15.5	10.2	5.3

industrial zone, as shown in Fig. 1. It is a modern park built mainly for the chemical industry, with the planned area of approximately 19.27 km^2. The planned area is located in the plot north of Zixin Road. It has formed a new chemical material sector centered on the Gulf Chemical Styrene and PVC Project, Yikai Rubber New Material Project, and Yangmei Hengyuan Polycarbonate Project. Meanwhile, it has formed a rubber processing and manufacturing segment with the core of Double Star Green Tire Unmanned Production Demonstration Project and Scrap Tire Recycling Project. The chemical logistics sector with the core of port terminal, railway logistics and chemical storage and transportation, as well as the supporting infrastructure of Sino French water affairs. Together, they build the basic elements of a modern chemical park. According to the "Qingdao Seawater Desalination Industry Development Plan (2017–2030)", the large-scale application of seawater desalination will be emphasized in Dongjiakou Economic Zone. The long-term water supply scale of the desalination plant will reach 300,000 cubic meters per day in the Dongjiakou Chemical Park by the "General Development Plan of the Chemical Park" (Petroleum and Chemical Industry Planning Institute 2018).

Forecast of total water consumption. Water demand analysis of industrial projects, water demand analysis of landscape environment, and water demand analysis in residential areas were conducted by General Development Plan of the Chemical Park, the results area, as shown in Table 3.

For the desalination plant, the current water supply scale is 100,000 cubic meters/day, the short-term water supply scale is 200,000 cubic meters/day, and the long-term water supply scale is 300,000 cubic meters/day.

The desalination plant is located to the east of Zhongxin Road in Dongjiakou Port District and south of Weishisan Road, with a total land area of about 150 acres "flocculation sedimentation + ultra-filtration" was designed as the pretreatment process and two-stage reverse osmosis as the main process.

The seawater is taken in planning area, pumped into the pretreatment process, and used for cooling water of Huaneng Power Plant. The effluent of the cooling sea water

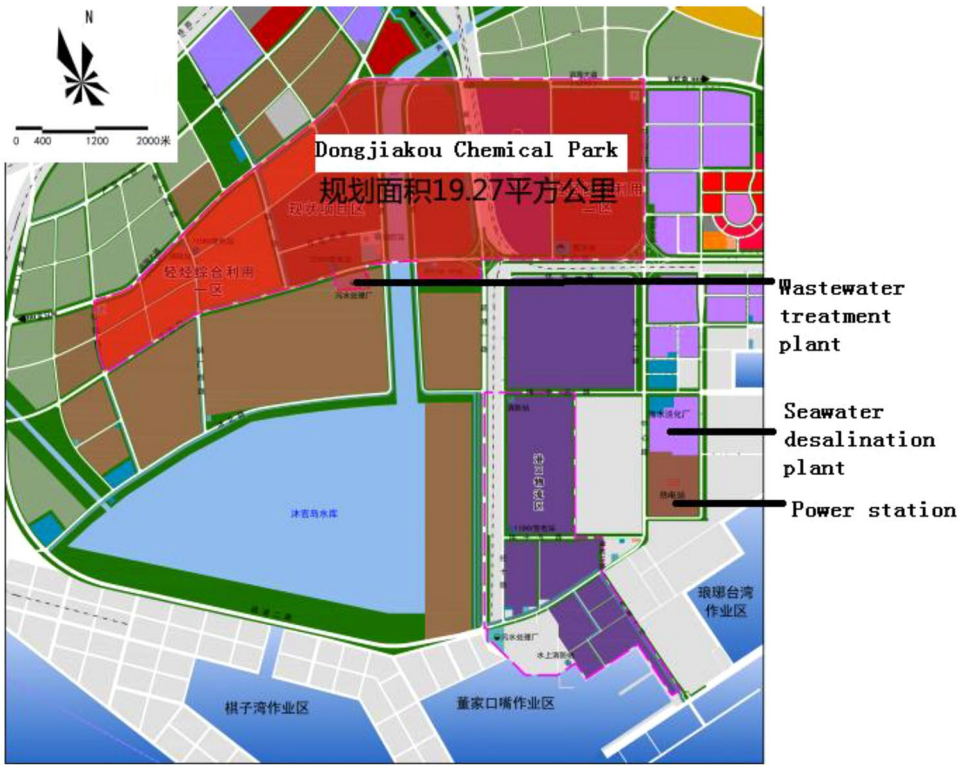

Fig. 1 Location of the seawater desalination plant

Table 3 Annual water demand at different term

Item	Industry		Landscaping	Domestic	Total		
	recycling	Municipal			recycling	Municipal	Summary
Current	2.42	8.34	0.41	0.04	2.42	8.79	11.21
Short term	4.52	15.58	0.46	0.07	4.52	16.11	20.63

Table 4 Seawater quality in Bahai Bay (Su Rao and Ye Chunsong 2007)

Number	Items	Unit	Range	Average
1	Turbidity	NTU	20–222	71.7
2	Suspend solid	mg/l	14–302	94.4
3	pH		7.96–8.11	8.07
4	Temperature	^{0}C	0–10	Variation with season
5	Total iron	μg/L	680–3767	1612.4
6	Active silicon	mg/l	0.92–4.26	2.72
7	Inactive silicon	mg/l	5.58–29.10	13.98
8	COD_{Mn}	mg/l	6.50–9.11	8.28

undergoing preliminary purification and heating, reducing the cost and energy consumption of preliminary purification of sea water will be pumped into the desalination plant nearby, as shown in Fig. 1.

Seawater used for cooling water

Water used in the thermal power plant is generally divided into two major parts: process water and non-process water (Wang and Liu 2014), of which process water accounts for about 95% of the water consumption of the plants, such as circulating cooling water, water for ash (slag), and boiler make-up water (Zhao et al. 2007). Seawater directly used for cooling water of the Huaneng Power Plant will save the water resource. Seawater quality in Bohai Bay is shown in Table 4. After treated by proper way, the water quality will meet the requirement of cooling water.

Two 350 MW super-critical coal-fired co-generation units were designed, and the unit adopts a direct-flow water supply system with seawater as cooling water. In summer, the seawater intake is 1.58 million m^3/day, and the circulating water temperature rises 9.12 °C; in winter, the seawater intake is 0.58 million m^3/day, and the circulating water temperature rises 13.87 °C. The seawater intake was arranged at the Huaneng Phase II wharf of the North Second Jetty. Set up a warm drainage outlet outside the west breakwater of Dongjiakou Port area (Marine Environmental Impact Assessment of Huaneng Dongjiakou 2×350 MW Combined Heat and Power Project 2015). As mentioned above, the amount of seawater used for cooling is enough to meet the amount of desalination.

Seawater desalination utilization plan

The desalination is designed separated from civil water supply, the main pipes of desalination plant pipe network lay along the north–south direction of Zhongxin Road-Jicheng Road, east–west direction, and along the north–south direction of Gangwang Avenue. Desalination branch pipelines lay along the municipal road network along Zhongxin Road South-Binhai Road-Gangwang Avenue to form a water supply network.

The desalination water will directly supply the chemical industry, such as Qingdao Gulf Chemical Co., Ltd., and Qingdao Double Star Group et al. The desalination water will be used as process water without further advanced treatment; it will save the cost of the company. Water for daily life or environment will be supply for municipal water supply system. Two separate systems designed in Dongjiakou Economic Zone.

Conclusion

Dongjiakou Economic Zone is located at the coastal line of Huangdao district, the location provides an excellent condition of using the seawater. The seawater quality meets the requirement of cooling water and desalination after proper treatment.

Two water supply systems designed in Dongjiakou Economic Zone, Seawater and seawater desalination are designed directly used in the thermal power plant and The Chemical Park of Dongjiakou Economic Zone; which will save the fresh water above 1.68 million m^3/day in summer, and 0.68 million m^3/day in winter using seawater. This strategy is very import for the water shortage city of Qingdao.

The thermal power plant and desalination were designed along each other, and seawater is used for cooling of the thermal power plant and then pumping to the desalination plant for desalination, which will save the energy for purification of the seawater and construction cost.

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Declarations

Conflict of interest The authors declare they have no conflicts of interest.

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