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Summary of Steam System Optimization and Energy Saving and Carbon Reduction Practice in Yanshan Petrochemical Company

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Abstract This paper analyzes the main problems of Sinopec Beijing Yanshan Petrochemical Co., Ltd., such as decentralized steam system layout, many types of fuels, obvious increase in fuel cost, low operation efficiency of turbine and boiler and high self consumption loss, and puts forward and implements optimization and improvement measures such as pressure raising transformation of natural gas system, adjustment of energy consumption structure, reduction of energy consumption cost, improvement of steam production quality and equipment efficiency. The results showed that compared with the fuel consumption in 2018, the consumption of coal coke was reduced by 550 000 t, the consumption of natural gas was increased by 170 000 t, and the total consumption of fuel gas and fuel oil was increased by 50 000 t, equivalent to 246 000 t of standard coal; the purchased electricity was increased by about 5×10^8 kW · h. Green power trading and 14.76 MW distributed photovoltaic projects were carried out. According to the calculation of 1 400 - 1 600 h annual power generation in class II photovoltaic areas and the emission factor of North China regional power grid baseline, the annual emission reduction was about 55 000 t CO_2 in 2021. After the above transformation, the goal of zero-coking is achieved; the steam consumption of units is reduced by 21.5%, the steam production of boilers is reduced by 24.9%, and the annual emission reduction is about 760 000 t CO_2, which has achieved good results.
Key words Steam system, Fuel structure, Energy structure, Equipment efficiency, Steam loss, Optimization, Energy saving, Carbon reduction

1 Introduction

Sinopec Beijing Yanshan Petrochemical Co., Ltd. (Yanshan Petrochemical Company), as a large petrochemical joint enterprise, always adheres to the function orientation of the capital, adheres to ecological priority and green development, comprehensively promotes energy conservation and emission reduction, and protects the ecological environment[1]. In order to minimize the impact of enterprise fuel cost and constantly improve the ability of green, low-carbon and high-quality development, fruitful work has been carried out in optimizing fuel structure, reducing steam consumption, adjusting energy consumption modes, saving energy and reducing carbon and green development through in-depth analysis of fuel composition and steam production and supply balance, evaluation of operation efficiency of boiler and turbine unit, steam equipment and steam pipe network for refining and chemical industry, comparison of design parameters and actual working conditions, verification of steam system self consumption and loss, and investigation of steam trap selection and configuration, which complete the clean transformation project of steam system with high quality, reasonably restrain the increase in energy cost of enterprises and reduces the actual energy cost.

2 Status of steam system

Yanshan Petrochemical Company has 63 sets of main production units and 68 sets of auxiliary production units, which can produce 94 varieties and 431 grades of petrochemical products, being one of the main production bases of synthetic rubber, synthetic resin, phenol-acetone and high quality refined oil in China. There are 20 boilers on active service in the company's steam system, with a total evaporation capacity of 3 220 t/h, including 9 high pressure and ultra high pressure boilers (including 3 boilers with circulating fluidized bed), and 11 medium-pressure boilers. There are 10 sets of steam turbine generator units (including 2 sets of abstraction-condensing units), with an installed gross capacity of 212.8 MW. Boilers are distributed in the east and west production areas, including 9 boilers in the west area, mainly for oil refining and rubber area, and 11 boilers in the east area, mainly for chemical area.

3 Existing problems

3.1 Decentralized system layout and many types of fuel

Yanshan Petrochemical Company currently has 20 boilers and 10 steam turbine generator units distributed in 3 thermoelectric workshops and 6 steam supply stations, with the farthest distance nearly 11 km, and the overall layout is decentralized. Under the influence of incomplete environmental protection facilities and overtemperature of superheater, there are 13 old boilers whose actual output is less than 50% of the rated load. Although there are many boilers running at the same time, the steam system still can not meet the requirements of safe steam supply, resulting in low safety factor and high energy consumption of the steam system.

Boiler fuels include coal, petroleum coke, fuel gas, natural gas, *etc.*, with coal coke 550 kt, natural gas 100 kt, fuel oil 80 kt

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and fuel gas 80 kt. There are the following problems in the implementation of clean fuel substitution. First, the supply capacity of existing natural gas pipelines is insufficient, so new gas pipelines need to be built to expand new sources of natural gas, or the existing gas pipelines need to be expanded and improved. Second, it is necessary to implement clean transformation of boiler system, transform the existing CFB boilers into gas furnaces, and build large capacity natural gas boilers to replace the original old boilers.

3.2 Significant increase in fuel cost After the implementation of clean fuel substitution, the advantages of low cost of steam and power generation will no longer exist. In 2018, the steam cost of the company was about 150 yuan/t. After replacing with natural gas, the steam cost is calculated according to the natural gas price of 2.477 5 yuan/m^3. The steam costs of high pressure, medium pressure and low pressure steam (fuel + power + auxiliary materials, power + auxiliary materials are calculated at 20 yuan/t) are 284.4, 277.3 and 258.0 yuan/t, respectively. At the same time, the unit cost of power generation is increased from 0.4 to 0.97 yuan/(kW · h), higher than the purchased electricity price of 0.617 yuan/(kW · h) over the same period[2]. According to the calculation of annual output of 9 160 kt steam and power generation of 3.5×10^8 kW · h in 2018, the fuel cost of the enterprise will increase by more than 1 billion yuan. Therefore, the energy structure of units must be adjusted to reduce the gas consumption of units. At the same time, the existing abstraction-condensing generator set will be shut down, and the purchased electricity will be increased to reduce the overall energy cost.

3.3 Low operating efficiency and high self consumption loss of turbine and boiler

3.3.1 Low operating efficiency of boiler. After the modification of low nitrogen combustion of boilers, due to the upward movement of flame center, the radiative heat transfer of water wall decreases and the temperature of boiler outlet rises[3], resulting in overtemperature of superheater, limited load capacity and high sewage discharge rate, and the thermal efficiency of operation is generally lower than 90%. The limited value of thermal efficiency of natural gas boiler under rated load is 92%, and the normal sewage discharge rate of heating power station boilers with desalinized water as recharge water should not be higher than 2%[4].

3.3.2 Low efficiency of turbine unit. In the practical operation of industrial turbine unit, there are some problems such as unreasonable steam distribution mode, large throttle loss of regulating valve, high vacuum and terminal difference of the condenser of the industrial condenser unit, resulting in the increase of loss and the decrease of efficiency.

3.3.3 High quality and low consumption of energy. Steam heating is used for winter heating. For example, the packaging plant is heated directly by steam, and 11 heating stations and some office buildings are heated by steam heat exchange. According to preliminary statistics, 15 t/h low-pressure steams are consumed.

3.3.4 Lack of trap management. There are many kinds of traps on site, but some of them are unreasonable. According to the working principle of steam trap, there are mainly mechanical, thermostatic and thermodynamic types[5]. The refining unit is mainly heated directly or indirectly by steam, and sufficient steam dryness (greater than 0.95) must be maintained. Condensate water needs to be eliminated in time, and mechanical steam trap is generally selected, while thermostatic trap is mainly selected for pipeline heat tracing. Delayed on-site drainage recovery will result in waste of softened water and heat loss, and the heat loss usually accounts for about 15% of steam heat. If there is internal leakage in the trap, the loss is up to 20% – 50% or even higher[6].

3.3.5 Leakage on site. There are running, bubbling, dripping and leaking phenomena in the steam system. Some steam pipes and tracing heat lines have been running for many years, and there are problems such as aging of insulation layer materials, and damage and cracking of protective layer. According to statistics, a 7.5 mm leakage point can lead to an annual steam leakage of 880 t in a 0.8 MPa steam system; a DN25 exposed pipeline with a length of 10 m will lead to an annual heat loss of 42 t steam, and regular maintenance and overhaul can reduce energy costs by 3%[7].

4 Optimization and improvement measures

The company has set up a special task force, and follows the principle of "full factor coverage, full caliber investigation, whole process control" and "source reduction, process control, end treatment" combination. Combined with "energy saving and consumption reduction, potential tapping and efficiency improvement" of steam system, measures such as "three reductions and three improvements" have been taken in accordance with the general requirements of reducing quantity and improving quality, that is, reducing the amount of steam, reducing steam grade, reducing the number of boilers, improving waste heat utilization rate, improving boiler efficiency, and improving power system support capacity. The specific measures are as follows.

4.1 Completing pressure raising transformation of natural gas system In order to eliminate the impact of insufficient natural gas supply, many schemes such as new gas source development, new pipeline laying, old pipeline expanding and old pipeline pressure raising have been explored and tried. Based on the overall safety evaluation of old pipeline, the main pipe of the existing DN500 natural gas pipeline is raised from 1.5 to 2.9 MPa, and the maximum transport capacity is increased to 3 000 dam^3/d. The DN350 pipeline from Fenghuangting sub-transmission station to refining unit is raised to 1.0 MPa. The pressure of the sub-transmission station to the hydrogen production and the thermoelectric natural gas pipeline is raised to 2.9 MPa, creating conditions for the substitution of clean fuels.

4.2 Adjusting energy consumption structure to reduce energy cost

4.2.1 Changing into motor drive. The energy consumption structure should be adjusted, and the economic and feasibility study on changing the drive of pure coagulation unit to motor drive in refining and chemical unit is carried out. Through process demonstration and site condition confirmation, it is confirmed that 5 pure condensing turbine units of refining and chemical unit have the feasibility of changing into motor drive. According to the comprehensive calculation of the corresponding steam cost and electricity price, the operating cost will be significantly reduced after changing into motor drive (Table 1). After changing into motor drive, the steam consumption is reduced by 123.1 t/h; the cost is reduced by about 19 000 yuan/h; the annual steam consumption is reduced by about 980 kt; and the electricity consumption is increased by about 2×10^8 kW·h.

Table 1 Comparison between steam turbine drive and motor drive

Tag number of units	Energy consumption		Steam level//MPa	Operation cost//yuan/h		
	Steam//t/h	Electricity//kW·h		Steam turbine drive	Motor drive	Cost comparison
K302	14.0	2 295	0.8	3 611	1 416	-2 195
K301	35.6	6 344	0.8	9 183	3 914	-5 269
G201	19.0	3 516	3.5	5 269	2 169	-3 100
G401	12.5	2 303	3.5	3 466	1 421	-2 045
GB551	42.0	9 470	9.2	11 944	5 843	-6 101
Total	123.1	23 928		33 473	14 764	-18 709

4.2.2 Strengthening the comprehensive utilization of waste heat. Through the investigation of low temperature heat resources, 8 waste heat recovery and comprehensive utilization projects, including comprehensive utilization of waste heat of xylene unit, have been implemented. There are still 5 low temperature heat comprehensive utilization projects that have the implementation conditions, such as hydrocracking and combined utilization of thermoelectricity and low temperature heat, and the scheme demonstration is being carried out. It is planned to implement the recovery and utilization by using exhausted steam ladder recovery, compression adapter or heat pump, lithium bromide refrigeration, waste heat power generation and other technologies[8]. After the completion of the project, it is expected to save 30 t/h steam, with an annual steam saving of 240 kt.

4.2.3 Optimizing power structure. According to the fuel structure, two condensing generation units are shut down, the annual spontaneous electricity is reduced by 2×10^8 kW·h on the premise of ensuring the safety of power supply in the substation, so as to increase the proportion of purchased electricity. The electricity price during peak, sharp, shoulder, off-peak periods should be concerned. Measures such as optimizing the operation mode of pump are adopted to strictly control the electricity consumption during the peak period and to reasonably reduce the cost of electricity. The basic electricity expenditure should be reduced, and the calculation methods of following the contract capacity, following the maximum demand and following the actual maximum demand must be timely calculated and adjusted. In response to the local power supply company's regulations on voltage quality and reactive power management of power system, the power factor of power grid is strictly controlled and adjusted between 0.90 and 0.96, and the corresponding monthly reduction reward of electricity charges reaches 900 - 1 000 000 yuan. The price of purchased electricity is reduced, and electricity market transactions should be actively participated to deeply collect transaction information, study and judge the trend of electricity price, ensuring that the electricity price is lower than the market transaction price of the same period.

4.3 Improving steam production quality and equipment efficiency For thermal systems, the analysis method based on the second law of thermodynamics is often used to analyze and study the energy conversion process. The main methods include "black box" analysis method, flow diagram analysis method and EUD image analysis method[9]. The following measures are taken according to the analysis results.

(i) Improving steam production capacity and grade. The boiler operation adjustment is strengthened to maintain high parameter operation, to improve the boiler load rate, and to reduce self consumption. According to statistics, when the main steam temperature is increased by 10 ℃, the heat consumption rate of the unit decreases by 0.25% - 0.30% under the same technical conditions[10]. Combined with the production process characteristics of refining and chemical units, efforts should be made to improve the temperature and enthalpy of by-product steam of waste heat boiler, such as reforming waste heat boiler of catalytic cracking unit, optimizing the process to improve the feed temperature and optimizing the process parameters of tower[11], so as to improve the comprehensive utilization effect.

(ii) Improving thermal efficiency of boilers. The flue gas loss of boilers should be reduced, which generally accounts for 30% - 50% of the total heat loss of the boiler, and the main measures are reducing flue gas temperature and reducing exhaust gas emissions[12]. The oxygen volume fraction of general fuel oil and gas boiler should be controlled below 2%, and the air leakage rate of tubular air preheater is less than 5%. The sewage discharge rate of boilers should be reduced, and dosing ratio, quality monitoring of boiler water and connected discharge control should be strictly performed, and the sewage discharge rate of boilers should be controlled below 1% as much as possible.

(iii) Adjusting the status of turbine unit. Some unreasonable operating conditions of turbine units must be eliminated. For example, in the actual operating conditions of a abstraction-condensing turbine unit, the inlet steam parameter is 9.21 MPa at 535 ℃, which is 6.80 MPa at 510 ℃ under high stage valve, and the loss is about 26 kJ/kg; the actual vacuum of the condenser is -82 kPa, lower than the requirement that the condensing pressure should be 0.012 - 0.017 MPa[13]. The terminal temperature difference of the condenser is 20 ℃, which exceeds the design value by nearly 10 ℃, resulting in the increase of throttle loss and cold end loss of turbine unit and the decrease of efficiency. After solving the above problems, the steam consumption can be reduced by more than 3% and the annual steam saving is up to 70 kt. Therefore, measures such as adjusting the steam distribution mode of unit and checking the leakage of vacuum system are taken to improve the operation efficiency of the unit.

(iv) Updating the pumping system. Some abstraction-condensing turbine units still use steam jet air ejector system. Generally, the steam consumption of steam jet air ejector is designed to be 0.5 t/h steam and the cost is about 1.03 million yuan/a. If the water jet air ejector system is used, it is generally equipped with two 30 kW water-jet pumps (one use and one standby), costing about 140 000 yuan/a. If the water ring vacuum pump system is used, its operating cost is about 40% of the water jet air ejector system, less than 60 000 yuan/a. Compared with the steam jet air ejector system, the steam can be saved by 4 kt/a and the cost can be reduced by 970 000 yuan/a.

After the implementation of the above projects and measures, it is expected that the self consumption and loss rate of the steam system will decrease by 2% – 3%, the steam self consumption and loss will decrease by about 150 kt/a, and the overall efficiency of the steam system will increase by more than 2%.

4.4 Standardizing daily management to reduce steam loss

4.4.1 Adjusting heating energy. Direct steam or heat transfer heating should be eliminated, and waste heat recovery and utilization can be adopted. Preliminary statistics show that it can save 15 t/h low pressure steam, and 43 kt steam can be saved in a heating season.

4.4.2 Standardizing trap management. Steam trap is selected strictly in accordance with its working performance, conditions and condensate discharge[14], and regulations on procurement, operation and maintenance of traps are formulated. The on-line leakage detection mechanism of trap is established, and the leakage problems in trap are found in time by means of trap detector and automatic monitoring instrument. After the material pipeline tracing hotline of each unit is put into operation in winter, a total of 10 881 sets of various traps have been put into operation, which consumed about 90 t/h steam. It is preliminarily estimated that it can save energy by more than 10%, save steam by 10 t/h and reduce steam loss by 12 kt/a.

4.4.3 Implementing heat tracing method for substitution. In view of the wide distribution and large quantity of heat tracing in material pipeline and instrument box, the feasibility of changing to electric heat tracing is explored to further reduce the consumption of steam and the number of on-site hydrophobic points.

4.4.4 Strengthening heat network management. Thermal insulation testing and treatment are carried out, and heat dissipation loss is tested on 177 steam pipelines (103 km in total) of the heat network system. A total of 44 pipelines, with a total length of 33 km, exceed the standard, among which the most serious one exceeds 195%. According to statistics, the average energy is saved by 3% – 13% after the thermal insulation effect is improved, the investment payback period is 1.2 a, and about 60 kt/a steam can be saved. The operation mode of steam pipeline is optimized, and 40 steam pipelines with a length of 20 km are stopped according to production requirements of units, to reduce unnecessary losses.

4.5 Optimizing the system layout and practicing green development

4.5.1 Optimizing system layout. After taking the optimization measures, the steam consumption in the west area is expected to be reduced by 200 t/h. Considering the boiler load rate, maintenance, inspection and backup, the steam demand can be met by rebuilding two CFB boilers and building a new 260 t/h boiler in the west area. The steam consumption in the east area is expected to be reduced by 64 t/h, so it is considered to keep 4 boilers in the second thermal power plant, No. 3 pressure furnace in the third thermal power plant, and build a 260 t/h boiler in the east area. Eleven old boilers are eliminated, and two central heating centers in the east and west areas are formed.

4.5.2 Focusing on green and low carbon and carrying out green electricity trading. In 2021, as one of the first pilot enterprises of green electricity trading in Beijing, the company successfully subscribed for 4.0×10^7 kW·h green electricity, accounting for 42% of the market share in Beijing. The construction of new energy projects is promoted, and the distributed photovoltaic project with an installed capacity of 14.76 MW is planned to be put into operation in 2022.

To sum up, after optimizing the project and energy saving measures, it is expected to reduce the annual steam consumption by 1 335 kt, increase the purchased power by 4×10^8 kW·h, and improve the steam system equipment performance by 2% – 3% (Table 2).

Table 2 Optimizing project and expected effect of energy saving measures

Energy saving measures	Annual reduction of steam consumption//kt	Annual increase in purchased electricity//kW·h	Performance improvement %	Cost reduction million yuan
Optimizing the electric energy structure and reducing the purchase price of electricity		2×10^8		70.60
Study the motor drive scheme to reduce steam consumption of units	980	2×10^8		149.60
Strengthening the comprehensive utilization of waste heat and improving energy efficiency	240			61.92
Improving steam production quality and equipment efficiency			2 – 3	38.70
Standardizing daily management and reducing steam loss	115			29.67
Total	1 335	4×10^8	2 – 3	350.49

5 Implementation effect

In recent 3 years, the company has carried out clean fuel substitution, steam system optimization, energy conservation and carbon reduction work, and completed the task of zero-coking and optimizing, upgrading, improving quality and efficiency projects as scheduled. The energy consumption structure of the company has been continuously optimized; the efficiency of units has been constantly improved; the self consumption loss has been continuously reduced; the steam consumption of the refining and chemical unit and the steam production of boilers have been reduced year after year. As a result, the cost expenditure of fuel is reduced and good ecological benefits are obtained.

5.1 Lowering cost expenditure Compared with the fuel production and consumption in 2018, the gas consumption of refining and chemical units in 2021 decreased by 21.5% (1 587 kt), and the steam production of boilers decreased by 24.9% (2 280 kt). The self consumption and loss rate of steam system decreased by 39% (690 kt); the self consumption and loss rate of steam system decreased by 3.6%; the self electric energy production decreased by 2.7×10^8 kW·h (Table 3), and the purchased electricity increased by about 5×10^8 kW·h. By optimizing and adjusting the operation mode of power grid and strengthening market transaction of purchased electricity, about 30 million yuan of basic electric charge was saved in 2021, and the power factor rewarded of 10 million yuan was obtained, with an average price discount of 0.05 yuan/(kW·h) and an annual saving of electricity purchase cost of about 140 million yuan.

Table 3 Comparison of steam production and consumption data

Item	2018	2021	Reduced value	Decreasing amplitude//%
Steam consumption of refining and chemical unit//kt	7 385	5 798	1 587	21.5
Steam production of boilers//kt	916.1	688.2	227.9	24.9
Self consumption and loss of steam system//kt	1 775	1 084	691	38.9
Self consumption and loss rate of steam system//%	19.38	15.75	3.63	18.70
Self electric energy production//kW·h	3.54×10^8	8.3×10^7	2.71×10^8	76.6

5.2 Reducing carbon emissions Compared with fuel consumption in 2018, the coal coke consumption in 2021 was reduced by 550 kt, and the natural gas consumption was increased by 170 kt; the fuel gas and fuel oil consumption was increased by 50 kt, equivalent to a reduction of 246 kt standard coal. Meanwhile, the purchased electricity was increased by about 5×10^8 kW·h. Based on the primary method provided by *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, it is equivalent to an annual reduction of about 700 kt carbon dioxide. Green electricity trading and 14.76 MW distributed photovoltaic project is carried out. According to 1 400 – 1 600 h annual power generation in class II photovoltaic areas and the emission factor of North China regional power grid baseline of 0.941 9 t CO_2/(MW·h), the annual emission reduction is about 55 kt carbon dioxide, and the total annual emission reduction is about 760 kt CO_2.

6 Conclusions

It is an important part for urban refining and chemical enterprises to realize "net zero" emissions by implementing zero-coking and clean fuel substitution, which is not only the role of social responsibility, but also the need of the survival and development of enterprises. Steam system optimization, adjustment of energy consumption structure, improvement of system efficiency, energy saving and consumption reduction are important approaches and effective measures for refining and chemical enterprises to achieve "carbon peak and carbon neutrality", which have significant effects on reducing energy consumption cost and enhancing core competitiveness.

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