The state of the art of long-distance gas pipeline in China

by Chengjia Shang and Fujian Guo

The state of the art of long-distance gas pipeline of China was reviewed in this paper. With the urgent demand of clean energy for economy growth and reduction of air pollution, more and more pipeline projects had been completed and have been launching in the past decades. Aiming at greatly increasing efficiency and saving budget, higher strength and larger-diameter pipes have been developed and applied for constructing long-distance pipeline projects in China. For example, X80 grade pipeline has been applied to the 2nd west to east gas pipeline (2nd WEGP) with a distance of 7,000 km. This is the longest pipeline built by X80 pipeline steel in the world. Comparing with the first west to east gas pipeline (1st WEGP) built by X70, the diameter increased from 1,016 mm to 1,219 mm, wall thickness from 14.6 mm to 18.4 mm, gas pressure from 10 MPa to 12 MPa, the transmission capacity increased from 17 bm³/a to 30 bm³/a. Taking account of the steel amount, construction cost and other market reason (almost 95% was supplied by domestic steel companies), the investment of the 2nd WEGP is almost as same as the 1st WEGP. Moreover, other long-distance pipeline projects are introduced in this paper, and the technology achievement for developing X80 pipe is also presented.

1. INTRODUCTION

Long distance pipeline is the best choice to transmit natural gas with the benefit of low cost and high efficiency. In China, the pipeline project started from early 1980s by using X52 and/or X60 grade pipeline steel, the pipeline distance was only several hundred kilometers. With the increasing need in natural gas in the eastern and southern developing areas, the long distance pipeline project from west to east part of China was completed in early 2000’s, with total distance of more than 3,000 km, by using X70 pipeline steel. The annual transmission capacity of this 1st WEGP is about 17 billion m³. The internal pressure of this pipeline in the diameter of 1,219 mm is 10 MPa. With the further increasing requirement of natural gas from both the driving force of economy and the restricting of clean energy, pipeline projects have been launched in recent years.
energy, the 2nd WEGP had been built during the period of 2007-2012. To reduce materials usage, increase transmit capacity and save construction cost, X80 grade of pipeline was designed for the trunk line. In addition, for the safety consideration, seismic regions and high population density areas were cataloged and anti-deformation pipeline steels and 25.6 mm heavy thickness pipe were used. It is very unique that not only 22.4 and 25.6 mm thicknesses longitudinal submerged arc welding pipes, but also spiral welding pipes were designed for the trunk line. Regardless, high Charpy impact energy was desired for arresting crack propagation, and this was successfully verified by real gas field burst test. In this review, the advantages of X80 steels applications in construction of world longest pipeline will be summarized; the state of the art of physical metallurgy and actual industry data will be introduced.

2. THE NATURAL GAS CONSUMPTION SITUATION OF CHINA

China relied mainly on coal energy in the past. Figure 1 [1, 2] shows the primary energy structure of China and the world. It can be seen that coal occupied 64% of total energy in China, but only 30% for the world. In the present situation, to supply sufficient energy for fast development of economy and cut down apparently air pollution caused by coal consumption, natural gas is widely considered to be the potential of future clean energy. However, it can be seen that the consumption of natural gas is only 5.9% in China, which is much less than that of 24% in the world from Figure 1. As natural gas is cleaner and less emissions than coal and oil, the use of natural gas in China is the first choice to replace coal.

With the energy structure adjustment and economic development, the natural gas market grows up rapidly in China. The natural gas consumption increased averagely by 14% annually between 2000 and 2015, and the “acceleration” trend is steady, as shown in Figure 2. It is estimated that the total consumption will reach 400×10^9 m^3 per year in 2020.

3. DEVELOPMENT OF NATURAL GAS PIPELINE PROJECTS IN CHINA

Generally, the end users of oil and gas resources are mainly in industrialized areas, while most of the oil and gas fields are in remote areas such as arctic, deserts and oceans. Therefore, long-distance pipelines are needed to transport oil and gas resources from remote areas to the consumption area, large-scale cross-regional transportation of oil and gas is inevitable.

Actually, the development of pipeline project using domestic steel products just began in later 1990s in China. From 1970s to 1980s, initial short distance oil pipelines were built by using imported pipeline steels, such as TS52K (API X52). Since 1978, the industrialization promoted by the government reforming and policy opening greatly has raised the energy consumption in economy developing areas, such as south and east coast cities. In 1990s, API X52-X70 grade pipeline steels were developed successfully by domestic steel companies. API pipeline steels gradually replaced the imported steels and were widely used in short distance pipeline constructions. In fact, the grade is only X60, the maximum diameter of natural gas pipeline is Φ660mm, and the working pressure is 6.4 MPa. From 2000, it becomes a new era, the long distance gas pipeline project developing rapidly in China. The first and second west to east natural gas pipeline were built and completed in succession.

The huge demand for the natural gas greatly promoted the pace of the construction of domestic oil and gas pipeline, and growth rate of total length of gas pipeline was extremely fast, as seen from Figure 3 [3]. In 2001, the total gas pipeline length of CNPC was less than 15,000 km, while it reached 50,000 km in 2014, the increase was higher than 200%. However, as the economy growth rate cut down from 2015, the growth rate of pipeline in CNPC slowed down. Nevertheless, the third west to east gas pipeline has been under constructing.
from 2015, as indicated in Figure 4. Moreover, the Russia to eastern China natural gas pipeline project started to be built last year and Xin-Yue-Zhe coal gas pipeline project operated by Sinopec has been approved. In future, the other forth and fifth pipeline projects will also be built.

4. DEVELOPMENT OF HIGH STRENGTH PIPELINE STEEL

High strength pipeline steels are benefit for constructing pipelines with thin wall thickness and higher gas pressure for capacity. Therefore, increase in the strength is a goal of developing pipeline steel technology. Figure 5 (15) schematically shows the development of pipeline steel in the world and in China. Before 1990, X60-X80 grade pipeline steels were successfully developed by TMCP and applied in the world to build long distance pipeline, especially in North America and Europe. At meantime, X100 and X120 pipeline steels were developing in the world. However, pipeline steel research and application started very late in China. As seen from Figure 5, the researches and industrial developing of X52 were almost 20 years later in China than the world. The industry products and application (first west to east gas pipeline project) of X70 started from 2000. Since 2001, significant progresses in researches and industrial development of high performance pipeline steels have been made to catch up with the world level.

The highlights of Chinese pipeline projects are listed in Table 1. The characteristics of five long distance pipeline projects in China are demonstrated, they reflect the level of long distance pipelines in China. Actually, increases in both the pressure and diameter of 2nd WEGP were significant by comparing with 1st WEGP and the transmission capacity of 2nd WEGP was enhanced from 17 to 30 bm^3/a. By comparing with the investment for building 1st WEGP and 2nd WEGP, it can be clearly seen the advantage of 2nd WEGP by using X80 grade, 1,219 diameter pipeline steel.

The construction of 1st WEGP was launched on July 4th, 2002, completed and used to transport gas on December 31st, 2004. It is the first world-class natural gas pipeline designed and build by CNPC, the annual gas output is 17 bm^3, and it transmits natural gas from Xinjiang Tarim Basin to Henan province, Anhui province, Zhejiang province and Shanghai city. The length of this pipeline is about 4,200 km, the scale of investment reaches 140 billion RMB, the steel grade is X70, wall thickness is 14.6 mm, diameter is 1,016 mm, and the design pressure is 10 MPa. The 1st WEGP is the milestone for the development of China natural gas pipeline industry.

<table>
<thead>
<tr>
<th>Project</th>
<th>1st WEGP</th>
<th>2nd WEGP</th>
<th>3rd WEGP</th>
<th>R-CEGP</th>
<th>XYZCGP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter/mm</td>
<td>1,016</td>
<td>1,219</td>
<td>1,219</td>
<td>1,422</td>
<td>1,219</td>
</tr>
<tr>
<td>Maximum Working pressure/Pa</td>
<td>10</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Wall thickness of spiral pipe/mm</td>
<td>14.7</td>
<td>18.4</td>
<td>18.4</td>
<td>22</td>
<td>18.4</td>
</tr>
<tr>
<td>Longitudinal pipe/mm</td>
<td>18.4</td>
<td>22.4</td>
<td>22.4</td>
<td>26</td>
<td>22.4</td>
</tr>
<tr>
<td>Trunk line length/km</td>
<td>4,200</td>
<td>7,000</td>
<td>7,378</td>
<td>3,170</td>
<td>8,280</td>
</tr>
<tr>
<td>Annual transmission capacity/bm^3</td>
<td>15</td>
<td>30</td>
<td>30</td>
<td>38</td>
<td>30</td>
</tr>
<tr>
<td>Investment/billion RMB</td>
<td>140</td>
<td>142</td>
<td>120</td>
<td>–</td>
<td>159</td>
</tr>
</tbody>
</table>
The 2nd WEGP started to build on February 22nd, 2008, it was completed and put into operation on December 30th, 2012. The annual gas transportation capacity is 30 bm/a. The total length of this project is more than 7,000 km from Xinjiang Horgos to Guangzhou and Shanghai. The total investment is 142.2 billion RMB. The pipeline steel grade is X80 and the diameter is 1,219 mm, the design pressure is 10~12 MPa. Table 2 shows the types and consumptions of X80 line pipe for the trunk and branch line of 2nd WEGP. It can be seen that percentages of SSAW pipes and LSAW pipes in the total usage are about 72% and 28%. The thickness of SSAW pipe is 15.3 mm and 18.4 mm respectively, the thickness of LSAW pipe is 22.0 mm, 26.4 mm and 27.5 mm, respectively. Table 3 shows the total consumption of X70 and X80 grade pipeline steels for 2nd WEGP.

The 3rd West-East Gas Pipeline project started to construct on October 17th, 2012, it is under constructing and will be put into operation soon, and the annual gas transmission capacity is 30 bm/a. The 3rd West-East Gas Pipeline project, including a truck line, eight branch lines, the total length is about 7,378 km, from Horgos port to Fuzhou, the total investment is about 120 billion RMB, the pipeline length is about 7,000 km from Xinjiang to Guangzhou and Shanghai. The total investment is 142.2 billion RMB. The pipeline steel grade is X80, diameter 1,016~1,219 mm, pipe design pressure 10~12 MPa.

Russia to China natural gas pipeline project starts form Heihe to Shanghai. The length of new construction line is 3,170 km. In the common witness of the two heads of the states, CNPC and the Russian gas company signed the ‘China-Russian natural gas purchase and sale contract’ on May 21st, 2014, the contract period is 30 years. The two sides agreed that Russia began to supply gas to China through the Russia - China natural gas pipeline project in 2018, with annual supply 38 billion m³. This pipeline project will be built by X80, the diameter is 1,422 mm, the pressure is 12 MPa.

In October 2015, the National Development and Reform Commission formally approved the Xinyuezhe coal gas pipeline project, marking that the project already has the conditions for construction. This pipeline project includes a main line, five branch lines, starting from Xinjiang Yining to the Shaoguan city in Guangdong Province, the total length is 8,280 km, the annual gas transmission capacity is 30 billion cubic meters, the total investment is 159 billion RMB. Pipeline steel X80 is used for this project, diameter is 1,219 mm and design pressure is 12 MPa.

5. THE MECHANICAL PROPERTIES OF X80 PIPELINE FOR 2ND WEGP

The main technical achievement of Chinese pipeline technology can be presented by the 2nd WEGP. It is the longest pipeline in the world built by X80 grade 18.4 mm thickness spiral pipe and 22.4 mm longitudinal pipe for the truck line. Nevertheless, before design and construction of the 2nd WEGP, the R&D and industry trial of X80 pipeline had been completed from 2003 to 2005. The demonstration section of 79 km long X80 pipeline in 1,066 mm diameter was constructed in 2005. From 2006, the second west-east pipeline project had started to design.

The design transmission capacity of 2nd WEGP is 30 billion m³/a. The length of the truck line is 4,895 km, and the diameter of the pipe is 1,219 mm with 184/22/26.4/275 mm thicknesses of the wall. Transport pressure is 12 MPa in the western section and 10 MPa in the eastern section. The X80 pipeline steel is employed in the trunk line with a total amount of more than 4,000,000 tons.

The low carbon higher niobium alloy design was firstly employed in X80 pipeline steels in North American pipeline projects [5]. The higher Nb content X80 steel exhibits a good strength/toughness balance and the alloy cost is lower. At the beginning of drawing up standards of X80 pipeline steel for 2nd WEGP, the international specification rules (API 5L and ISO 3183), in which the limitation of niobium addition is 0.06 wt %, were considered. However, due to the demonstration of the North American application and some prior research results from overseas [6], the new concept that the content of niobium exceeded 0.06% at low carbon content was accepted by the Chinese pipeline industry and Chinese metallurgy community [7, 8]. The upper limit of niobium content was modified as 0.11%, the total content of Nb+V+Ti is not allowed higher than 0.15%. Results from Chinese steel mill trials and physical metallurgy researches [9-13] have suggested that the higher Nb X80 is capable to meet the requirement of X80 pipeline specification. Furthermore, both laboratory research on weldability of higher Nb content steels [14] and industrial trials were carried out to reveal the relationship of welding process and the toughness of X80.

<table>
<thead>
<tr>
<th>Table 2: Types of X80 line pipe and consumptions of 2nd WEGP</th>
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<tbody>
<tr>
<td>Types of pipe</td>
</tr>
<tr>
<td>SSAW</td>
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<td></td>
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<tr>
<td>LSAW</td>
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<table>
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<tr>
<th>Table 3: Total consumption of pipeline steels for 2nd WEGP</th>
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<tbody>
<tr>
<td>Steel grade</td>
</tr>
<tr>
<td>X80</td>
</tr>
<tr>
<td>X70</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>
parameters-microstructure-mechanical properties in the HAZ.

Table 4 shows the specification of X80 for 2nd WEGP comparing with X70 for the 1st pipeline. It can be seen that with increase the strength grade and wall thickness, the CVN impact energy requirement increase too for guaranty the operation safety (arrest the ductile crack propagation).

Table 5 shows the typical chemical composition of X80 for strip and plate. It is a HTP concept [5,6] pipeline steel, with maximum Nb content of 0.11. As the Mn can be act as both strengthening and phase transformation control element, by optimized TMCP, composition the plate of X80 can be Mo free for saving cost at that period.

Statistical results of tensile tests from 1455 heats of spiral welded pipe for 2nd WEPP are shown in Table 6. Production test data of strip steel from four mills (A, B, C, D) is included. All the data meets the required specification. The average yield ratio is about 0.86.

The statistical results of Charpy impact tests from 1,297 heats of spiral welded pipe body are shown in Table 7. Manufacturers’ test data of plate coil for making tubes from four mills (A, B, C, D) was included. The average Charpy impact energy of the pipe body was about 350 J, and all the average shear areas were 100%. The Charpy energy of the pipe body and plate coil were similar. All tested Charpy energies are above the specified minima. That shows an excellent impact toughness of low carbon high niobium steel.

The statistical results of DWTT tests from 1561 heats of spiral welded pipe body are shown in Table 8. The DWTT results of the X80 tubes made by hot strip steel from four mills are acceptable. Average shear areas are 90-96 %.

6. CONCLUSION AND PROSPECTS

Clean energy is of significance for sustainable development. Despite of fast development of green energy such as wind and solar etc., natural gas is an irreplaceable primary energy for environment protection. Continuously increasing natural gas supplying would be an urgent challenge in Chinese primary energy market.

Development of high efficiency gas transmission pipeline will be a long term task for the oil and gas companies in China. The global technology improvement for higher capacity and higher safety gas transmission will
promote the development of Chinese oil and gas transmission program. High strength pipeline steels contributed greatly to the success of construction high efficiency pipeline projects, such as 2nd WEGP. Higher grade steels of X90 and X100 are needed to be developed with the increasing transport capacity request for future pipeline projects in China. The breakthrough improvement of Chinese pipeline technology is also desired for the construction of the next round of pipeline projects.

REFERENCE


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