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The current situation and prospect of oil steel pipe in China

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Abstract: The oil steel pipe in the petroleum industry is very important for its high price, large consumption volume and great effect on the development of petroleum industry. The oil steel pipe mainly includes oil well pipe (drill pipe, drill collar, casing and tubing etc.) and oil-gas transportation pipe. This paper is an attempt to make a comprehensive review on the current situation and prospect of the oil steel pipe in China, presenting the past, today and future of the China oil pipe. The first section is a historical review of the China oil pipe. The developing course and progress of the oil steel pipe products are presented. The second section is about the current situation of the China oil pipe. The general situation of the China's steel pipe corporation and their products types, capability, etc. is introduced. The third section is about the prospect of the China oil pipe. This part mainly describes the new product research and development in China steel pipe corporations, which are facing more and more strict technical requirements of the petroleum industry in oil pipe, and reveals the prosperity of China's steel pipe corporations.

Key words: oil steel pipe; tubing and casing; transportation pipe; review; situation; prospect

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1 Introduction

1.1 Steel pipe is the base of petroleum industry

Oil steel pipe mainly includes two kinds of pipes: oil-well pipe (drill pipe, drill collar, casing, tubing, etc.), and the transportation pipe of oil and gas. The well-drilling during the oil exploration and exploitation needs drill pipes and drill collars, well reinforcing needs casing, and the oil recovery needs tubing. According to the statistics data, for 1 meter well, 62 kg oil well pipes are needed, including 48 kg casing, 10 kg tubing, 3 kg drill pipes, 0.5 kg drill collars, etc. In recent years, the annual consumption of oil well pipes is about 1.3 million tons. The pipeline transportation is the most economical and reasonable method for oil and gas. With the rapid development of pipeline, the demand of oil and gas transportation line pipe increases greatly in China. Several years ago, line pipes accounted for only 1/3 of oil well pipes in the demand, and in 2003, the demand for transportation line pipes exceeded 1.4 million tons.

In 2003, the consumption of seamless pipes in China is 6.6 million tons, including 19% oil well pipes (1.26 million tons). The welded pipes consumption of China is 10 million tons, including 14% oil and gas

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transportation pipes, 1.4 million tons. The quantity of pipes used in petroleum industry is only less than that in architecture industry.

1.2 The quality and performance of steel pipe have important effect on the petroleum industry

Firstly, the oil steel pipe plays an important role in the petroleum industry, which is required with a large quantity and costs more money. The investment in the oil pipe accounts for about 20% of the total in the petroleum industry.

Secondly, the quality and property of oil steel pipe have important effect on the development of the petroleum industry. The service condition of OCTG is very strict. For example, the tubing and casing strings are required to support the inside and outside pressure, up to hundreds to thousands of atmosphere pressure, as well as hundreds tons of tensile loads, and meanwhile they are always affected by high temperature and severe corrosion medium. Before 1985, there were about 1000 accidents in China every year, which were related to the drilling strings rupture. According to the statistics released by IADC, the mean value of the expense for every accident was 106000 $. On one hand, the accidents relating to the drill strings or the casing strings may sometimes lead to the discarding of the oil well. In addition, the life of casing directly determines that of the oil well, and the life of the oil well determines that of the oil field. On the other hand, the accidents relating to transportation pipe are more disastrous. The safety and reliability, the life and the economy of oil steel pipes are related to the petroleum industry closely.

1.3 The strict quality and property requirements to OCTG by petroleum industry push the development of steel & iron industry

To satisfy the severe service condition of oil well and transportation pipes, the requirements to chemical composition, mechanical properties, metallurgical quality and dimension precision are all strict. Iron & Steel industry has been supporting the petroleum industry, and is the base of it. In the mean time, the development of the petroleum industry also pushes the technical progress of iron & steel industry (oil steel pipe industry). For example, the main drive of line pipe and pipeline steel development is the more and more strict quality requirements put forward by oil and gas transportation projects. In the recent 30 years, pipeline steel has become the most vigorous and important embranchment in the field of low alloy & high strength steel and microalloy steel. In the world, the oil steel pipes manufacturing corporations are all steel manufacturers famous for their advanced technique and having enjoyed high fames. In China, to realize the self-supporting of oil steel pipes, the government invested to build TPCO and BAOSTEEL with the most advanced foreign equipment and technologies at that time.

2 Historical review of the development of Chinese oil steel pipe

2.1 Historical review of oil well pipe

China has a long history of the oil well pipe production. But during 1950s to 1970s, the producing technique was backward, that the quantity, types and quality of the oil well pipes could not meet the demands of the development of the petroleum industry. Since 1978, China has started to make great efforts in realizing the self-supporting and the output of pipes has been somewhat increased. otherwise, the annual demand has rapidly increased from 2.9×10^5 t in 1981 to about 9×10^5 t in 1990. For example, in 1989, the consumption was 8.9×10^5 t , and till 1989, the quantity of total oil well pipes produced by the domestic factories has been 8.12×10^5 t . That is to say, the total output in 30 years cannot meet the demand of one year. From 1949 to 1994, the imported quantity was 1.15×10^7 t, and the domestic output was 1.2×10^6 t. The self-supporting ratio was only 10%.

Since 1990, led by the Metallurgy Ministry and CNPC, the production and application enterprises have done their best to increase the self-supporting ratio. Especially after baosteel and the Tianjin Pipe Co., Ltd (abbr.: TPCO) put into production, the self-supporting ratio rapidly increased from 10% in 1989 to 50% in 1996, 60% in 1997, and 80% in 2003 (see Table 1 and Figs. 1, 2).

Table 1 Quantity list of consumption and self-support for Chinese oil well pipe (1987—1998)

Years	Consumption/10^4 t	Import quantity/10^4 t	China quantity/10^4 t	Self support ratio/%
1987	80.78	66.88	4.25	5.26
1988	88.10	88.39	8.87	10.07
1989	89.87	84.30	9.45	10.57
1990	86.87	55.83	13.74	15.82
1991	94.41	89.27	13.67	14.48
1992	94.16	50.56	17.92	19.03
1993	84.90	54.43	15.58	18.35
1994	86.27	79.54	17.05	19.75
1995	81.60	42.14	27.04	33.13
1996	82.89	22.46	43.17	52.11
1997	85.00	34.00	51.00	60.00
1998	87.10	31.81	66.60	76.46

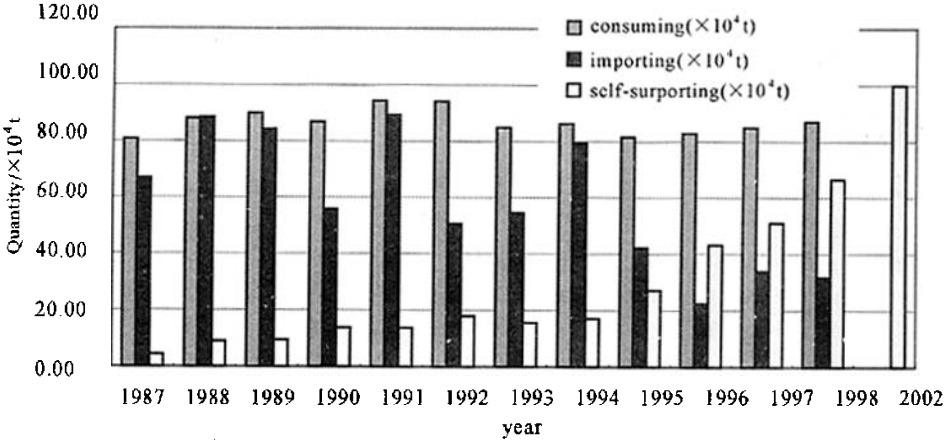

Fig. 1 Quantity of consuming, exporting, self-supporting for Chinese oil well pipe

All the drill pipes and drill collars needed in China are manufactured by ourselves now, which were imported before 1980.

Now, China is no longer a country mainly depending on the import of oil well pipes, but a country which can meet most of its own demand in oil well pipes and even export some to other counties.

2.2 Historical review of the oil and gas transportation pipe

Transportation with pipeline is the most economical and reasonable manner for oil and gas. Now the length of all the pipelines in the world exceeds 2.30×10^6 km, and increases with the speed of $2\times10^4-3\times10^4$ km/year. In China, long distance oil pipeline construction started from 1958, and its long distance gas

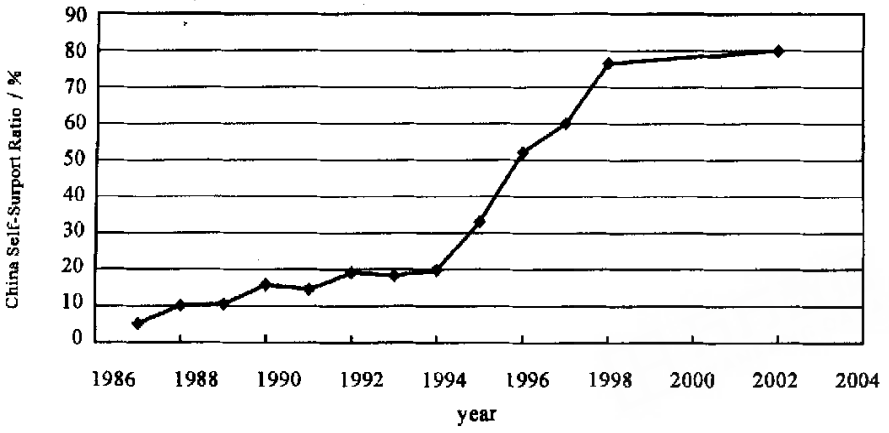

Fig. 2 Oil well pipe self-supporting ratio increases with the year

pipeline construction started from 1963.

The Chinese ancestor started the natural gas transportation with bamboo in 600 BC, and then English started transporting with the wood pipes. It was very dangerous. The large diameter pipeline developed in America at the beginning of 20th century. In 1926, API issued API 5L recommended practice that includes 3 carbon steel grades. API 5LX issued in 1947 added with X4, X46, X52. API 5LS issued in 1964 standardized the spiral pipe. API 5LX and 5LS issued during the course of 1967—1970 added with X56, X60, X65, and in 1973 it added X70. In 1987, API 5L (the 36th edition) incorporated API 5LX and 5LS. Now API 5L (the 36th to 43th edition) includes 11 grades (A25, A, B, X42, X46, X52, X56, X60, X65, X70, X80). The X100 and X120 have developed successfully, but they are not included in API and ISO. The pipeline pressure has increased from 0.25 MPa in 1870 to 6.2 MPa during the course of 1950—1960, to now above 10 MPa (maximum about 20 MPa).

The spiral welding pipes used in the Chinese long distance oil & gas transportation pipeline, mainly produced by the 6 welding pipe factories (Baoji Petroleum Steel Pipe Co., Ltd., North China Petroleum Steel Pipe Co., Ltd., Shashi Petroleum Steel Pipe Co., Ltd., Liaoyang Petroleum Steel Pipe Co., Ltd., Ziyang Petroleum Steel Pipe Co., Ltd., Shengli Petroleum Steel Pipe Co., Ltd.). The spiral welding pipe is now fully self-supplied. The X80 SSAW has developed successfully. From 2000, these 6 factories have reconstructed the SSAW production line in a large scale, improving the forming and welding technology, enhancing the on-line inspection, and supplying the pipe end expansion. As a result, the quality of SSAW has been improved. A lot of inspecting data indicate that the domestic SSAW's quality is the same as that of the imported UOE pipe in mechanical properties of pipe body, heat affected zone and weld, including CVN and DWTT. The full-scale burst test stress of domestic SSAW is a bit higher than the imported UOE pipe.

The hot-rolling coils used by SSAW mainly are A3 16Mn produced by Ansteel etc. during 1950th to 1970th, and TS 52K(the same as X52)made in Japan during the end of 1970th to 1980th. In 1990th, the X52, X60, X65 hot-rolling coils used in Tarim oil and gas pipeline, Shan-Wu gas pipeline, Ku-Shan oil pipeline and Shan-Jing gas pipeline, are mainly supplied by Baosteel and Wusteel. Now, Ansteel, Bensteel, Taisteel, Meisteel etc. can also produce the high grade X series hot rolling coils. The X70 grade hot-rolling coils has been used in the West-East gas pipeline and the 2nd Shaanxi-Beijing gas pipeline that are being built now, are mainly supplied by Baosteel and Wusteel (a little part is from POSCO). The X80 hot rolling

coil has developed successfully by these two corporations.

Before 1997, China had not one set of large diameter LSAW production equipment. In recent years, the JCOE and UOE pipe made in Julong steel pipe Co. and Panyu Zhujiang steel pipe Co. have filled up the blank in LSAW pipe production field.

In the past, the wide and thick steel plate to produce the LSAW pipe relied on import. Now through developing techniques, Wuyang Steel Co. and Anshan Steel Co. have developed API X series grade wide and thick steel plate successfully that are below X80 which has been used in the West-East gas pipeline and the 2nd Shaanxi-Beijing gas pipeline. Now the development of API X80 wide and thick steel plate is almost completed. The wide and thick steel plate production line has been built in Baosteel, meanwhile the UOE product line is about to start-up.

In China, ERW pipes are mainly used in the branch pipelines and the city pipeline networks, and a part of them are used in the main pipelines that have middle or small diameter. There are a lot of manufacturers of it. The representative manufacturer is Baoji-SMI Petroleum Steel Pipe Corporation.

3 The current situation of the development of Chinese oil steel pipe

Here is a brief introduction to the general situation, product types, and capability of the Chinese petroleum steel pipe corporation.

3.1 The current situation of oil well pipe

Oil well pipe mainly includes tubing, casing (seamless pipe and ERW pipe), drill pipe, drill collar etc.

3.1.1 Tubing and casing

At present, the main oil well pipe producers in China are TPCO, Baosteel, Wuxi Seamless Co., Ltd. (abrr.: WSP), Hengyang Hualingsteel Co., Ltd., Chengsteel, Baotou, Ansteel, Jiangsu Chengde steel pipe Co., and Baoji-SMI Petroleum Steel Pipe corporation etc.. The total capacity of them is above 1.5 million tons for every year. The production volume of TPCO, Baosteel, and WSP accounts for above 80% of that on China's market. Table 2 illustrates the general situation of the main petroleum steel pipe corporations of China.

Table 2 Brief introduction to main tubing & casing producer of China

Name	Capacity /(10^4 t · a^{-1})	Total sold /10^4 t	Total export /10^4 t	Sold in 2003 /10^4 t	Exporting in 2003 /10^4 t	Product line	D/mm	T/mm	Built time
TPCO	70	305.36	46.63	51.88	14.49	5	48.0-244.5	3.5-35	1989
Baosteel	45	250.00	58.44	40.00	8.56	3	73-177.8	6.2-13.84	1978
Wuxi Seamless	20	60.00	8.00	18.00	2.00	3	73-339.7	6.2-13.84	1999
Hengyang Hualingsteel	40	20.00	8.00	6.00	2.00	3	48.3-339.7	3.5-13.84	1958
Baoji-SMI	10	14.00	—	2.75	—	1	139.7-339.7	5.87-12.7	1958

Each corporation has been granted the right to use the API Monogram, and has got the ISO9000 quality system certificate, and has passed the environmental certification of ISO14001. In the meantime they all obtain the Industry Production Permission Certificate issued by the Chinese government. The manufacturing level has reached the advanced level in the world.

The production types not only cover the entire API grade, i.e. H40, J55, K55, M65, N80, L80, C90, T95, C95, P110, Q125, but also include many non-API pipe types, such as high collapse resistant pipe, H_2S

resistant pipe, etc. And the self-production series have been developed. As for the thread, the production have covered all the API types, such as: LC, STC, BC, XC, etc.. In addition, the special thread tubular series have been developed. So the domestic oil well pipe can meet different requirements and various choices.

The non-API series of TPCO:

(1) high collapse series:TP80T,TP110T,TP110TT,TP125TT,TP130TT,TP140TT;

(2) thermal recovery well series:TP65H,TP90H,TP100H,TP110H,TP120TH;

(3) H_2S resistant series:TP80S(S),TP90S(S), TP95S

(4) low Cr & CO_2 resistant series:TP80NC-3Cr,TP110NC-3Cr;

(5) high strength and high toughness series:TP65,TP90,TP100,TP125,TP140V;

(6)fatigue resistant series for high pressure well:TP80CQJ,TP110CQJ;

(7) drilling casing series:TP55D;

(8) special thread joint series:TP-CQ;

(9) non-API dimension series:Φ152.4×16.9 mm, Φ250.8×15.88 mm, Φ254.0×16.74mm, Φ193.7×17.14 mm.

The non-API series of BAOSTEEL:

(1) high collapse series:BG-80T, BG-95T, BG-110T, BG-125T

(2) low temperature series:BG-80L, BG-95L, BG-110L, BG-125L

(3) H_2S resistant series:BG-80S, BG-95S, BG-80SS, BG-95SS

(4) deep well series:BG140, BG150;

(5) economical series:BG70

(6) special thread joint series:BGT, BGT1, BGC, HSC, SUPERMAX

(7) economical CO_2 resistant series:BG55-1Cr, BG80-1Cr, BG95-1Cr, BG110-1Cr, BG80-3Cr, BG95-3Cr, BG105-3Cr

(8) economical CO_2+H_2S resistant series:BG80S-3Cr, BG95S-3Cr

(9) strength series:BG60, BG65, BG70, BG75

(10) thermal recovery well series:BG-D60、BG-D80

(11) Non-standard XC casing series: 4″, 4-1/2″, 5″, 6-1/4″

The non-API series of Wuxi Seamless:

(1) thermal recovery well series:WSP-105H, WSP-80H

(2) high collapse resistant series:WSP-110T

(3) corrosion resistant series: WSP-90C

(4) special thread series: WSP-1T, WSP-2T, WSP-3T.

The statistics indicate that, for the oil well pipe, in 2003, the import volume was 220628 tons, and the export volume was 270965 tons. This was the first time "export exceeds import" for oil well pipe in China. For example, TPCO exported 1.9×10^5 t seamless pipe in 2003, worth 100 million dollars. There were 150000t oil well pipe exported, occupying 79% of total, with an increase of 55% than that in 2002. This occupied 56% of the Chinese oil well production export quantity in 2003. The oil well pipes exported by Baosteel and Wuxi Seamless were 85600t and 20000t in 2003. It can be predicted that the export volume will achieve 9.6×10^4 t and 5.0×10^4 t in 2004.

At present, the oil well pipes produced by TPCO, Baosteel, Wuxi Seamless, Hengyang Hualingsteel Co., Ltd., etc. have been exported to more than 40 countries, including: America, Canada, Russia, Netherlands, Spanish, Mexico, Switzerland, Australia, Japan, Korea, Philippine, Thailand, Malaysia,

Singapore, Indonesia, India, Vietnam, Burma, Saudi Arabia, United Arab Emirates, Iran, Sudan, South Africa, etc., and the export volume of tubing and casing reflects the trends nowadays (see Table 3).

Table 3 Export statistical data of BAOSTEEL pipe (2000—2004)

Unit: 10^4 t

Years	Tubing and casing	Drill pipe	The other tubular
2000	6.3	0.08	4.8
2001	7.1	0.1	3.8
2002	5.5	0.2	3.7
2003	8.2	0.36	4.2
2004	9	0.6	4.5

3.1.2 Drill pipe

The representative drill pipe producers in China are Shanghai Baosteel, Jiangsu Grant Drill Pipe Co., Ltd, and Bohai NKK Drill Pipe Co., Ltd, etc. The capacity of them is 56800t/year. The API drill pipe with E75, X95, G105, S135 grade can be supplied.

Baosteel was built in 1978, with annual capacity of 2×10^4 tons. The total drill pipe sale achieved 1.5×10^4 t in 2003, and the same Figure is predicted to achieve in 2004. Its products covers all API grades with diameter 2-3/8" to 5-1/2", and additional several non-API types including high anti-twist drill pipe BGDS and high strength drill pipe V150, etc.

Jiangsu Grant Drill Pipe Co., Ltd. supplies various dimensions of drill pipes (2-7/8", 3-1/2", 5") adopting America equipment and technology. Its capacity is near 2×10^3 t/year. This corporation got the API qualification and ISO9001 quality system certificate in 1996.

Bohai NKK Drill Pipe Co., Ltd. was established by using the investment of China Petroleum Materials Equipment General Company, North China Petroleum Management Bureau, NKK, Marubeni-Itochu Steel Inc and Mitsubishi in December 1995. This corporation produces and sells series of drill pipes whose outside diameters are from 2-3/8" to 5-1/2" and steel grades are from E75 to S135 in accordance with API standards. Its products also include double shoulder drill pipes with high anti-twist ability and BNK C95S drill pipes that are of special steel grades and can be used in oil well containing sulphur. The equipment is imported from NKK and the technology is developed by NKK based on the technology introduced from the American Hughes Tools Co., Ltd. in 1976. Its annual production capacity is 16800 tons.

The general situation of each corporation is shown in Table 4.

Table 4 Brief introduction to main drill pipe producer of China

Name	Capacity /(10^4 t·a^{-1})	Total sold /10^4 t	Total export /10^4 t	Sold in 2003 /10^4 t	Product line	Dimension	Grade	Built time
Baosteel	2	8	1.5	1.5	1	2-3/8" to 5-1/2"	E/X/G/S	1978
Grant	2	2	1	1.98	2	2-3/8" to 5-1/2"	E/X/G/S	1990
Bohai-NKK	1.68	5.53	1.14	1.1	1	2-3/8" to 5-1/2"	E/X/G/S	1995

3.1.3 Drill Collar and the other drilling tools

The representative drill collar producers in China are Shanxi Fenglei Machinery Manufacturing Co. Ltd. and Shanxi Machine Tool Works.

Shanxi Fenglei Machinery Manufacturing Co, Ltd. has a drill collar producing history for more than

twenty years. In 1978, this corporation manufactured the first drill collar. It has been granted the right to use the API Monogram, and has get the ISO9002 quality system certificate, ISO14001 environment system certificate, and ISO18000 occupation healthy system certificate. It is the main drill tools supplier of CNPC, SINOPEC, CNOOC, etc.. Its production not only apply on inshore or offshore China, but also export to more than ten countries, i. e. Syria, Iran, India, Canada, Tunis, Turkmen, Kazakstan, Pakistan, Sudan, Cartel, Indonesia, America, Mexico, Venezuela, Iraq. The main products are drill collar, spiral drill collar, no-magnetism drill collar, full scale aggravate drill pipe, spiral aggravate drill pipe, no-magnetism aggravate drill pipe, square drill pipe, etc.

Shanxi Fenglei Machinery Manufacturing Co, Ltd. annual production capacity: 3000 t aggravate drill pipes, 5000pcs square drill pipes, 5000 pcs drill collars, and 200 sets drill tools. Till 2003, its total selling quantity has achieved 46658 pcs, and export volume has been 6194 pcs. There were 8241 pcs produced and 2330psc exported in 2003, accounting for 17.6% and 37.6% of the total.

3.2 The current situation of the oil and gas transportation pipeline

China's current total capacity for manufacturing SSAW and LSAW pipes has exceeded 2 million tons every year after a vast technology reconstruction. And the grades have coverd API spec 5L A, B, X42-X80. The production standards confirm to API SPEC 5L, ISO3183, GB9711 and the supplemental technical requirement of consumers (see Tables 5 and 6).

Table 5 Brief introduction to main SSAW producer of China

Name	Capacity /(10^4 t · a^{-1})	Total sold /10^4 t	Product line	D/mm	T/mm	Grade	Main consumer
Baoji	33	350	5	219-2400	5.2-20.0	X80 below	West to Esat, Ta-Lun, Jing-Xi, Ku-Shan, India, Sudan, Se-Ning-Lan, Lan-Cheng-Yu, Indonisia, Zhong-Wu, Xian-Bao, Jing-Xian, Chuan-Xi-Lan, Kela No. 2, Shan-Jing No. 2, etc. more than 40 pipeline
Huabei	42	100	5	219-2200	6.0-20.0	X80 below	West to Esat, Shan-Jing No. 2, Ha-Yi, Shan-Jing, Lun-Ku, Sudan, Se-Ning-Lan, Lan-Cheng-Yu, etc.
Shashi	12	120	2	273-1620	6.0-25.4	X80 below	West to Esat, Southwest, Shan-Jing, Desert, Ji-Qing, Yong-Hu-Ning, etc.
Liaoyang	15	100	3	219-1820	6.0-20.0	X80 below	Shan-Jing, West to East, Northeast, Se-Ning-Lan, Lan-Cheng-Yu, Sudan, Shan-Jing No. 2, etc.
Ziyang	11	70	2	273-2400	6.0-20.0	X80 below	Ba-Yu, Mo-Xi, Zhang-Deng, Ping-Cheng, Desert, Se-Ning-Lan, Lan-Cheng-Yu, West to East, Shan-Jing No. 2, etc.
Shengli	20	60	3	219-2200	6.0-20.0	X80 below	Shan-Jing, Sudan, Dong-Lin, Zhng-Ji, Guang-xin, Liao-Tai, Cang-Tian-Yan, Ji-Qing, Yong-Hu-Ning, West to East, Kazakstan, Sudan, Jing-Xi, Hang-Hu, Southwest, etc.

For SSAW pipes, there are only 6 manufactures mentioned in above paragraph which annual capacity has exceeded 1.33 million tons, and diameter and thickness range of pipe that they produced are 219—2400 mm, 5.2—25.4 mm respectively, and the type is above 50 kinds. Till the end of 2003, the total quantity of SSAW for manufacturing and selling has been 8 million tons. LSAW pipes now are only in its birth phase in

China, while the production capacity has already exceeded 7.0×10^5 t/year, with 304—1422 mm diameter, 6.0—26.4 mm thickness. From 2001 to 2003, the total quantity of LSAW for manufacturing and selling was 0.36 million tons.

Table 6 Brief introduction to main LSAW producer of China

Name	Capacity /(10^4 t·a^{-1})	Total sold /10^4 t	Product line	D/mm	T/mm	Grade	Main consumer	Built time
Julong	15	25	1(JCOE)	406-1422	6.4-26.4	X80 below	West to East, Shan-Jing No. 2, South of Henan, etc.	2000
Shashi	15	1.1	1(JCOE)	304-1422	6.0-32	X80 below	Southwest, etc.	2002
Panyu	20	18	2(UOE/JCOE)	406-1118	6.4-25.4	X80 below	Chunxiao project, Shell of CNOOC, Hainan, and many city gas line net	1999
Wanchi	15	—	1(JCOE)	406-1422	6.4-26.4	X80 below	—	2003

Each manufacturer has been granted the right to use the API Monogram, and has obtained the ISO9002 quality system certificate, ISO14001 environment system certificate, and gained the manufacture permission certificate of industry production issued by the Chinese government.

With rapid development, Chinese manufacturing industry of oil and gas transportation line pipe, can not only supply pipes to the domestic pipelines, but also export thousands of tons pipes to more than 50 countries, such as, Sudan, India, Korea, Mongolia, America, Italian, Australia, Philippine, Pakistan, Kazakstan, etc.

In 1998, Muglad Basin Oil Development Project, Sudan, X65, Φ711 mm×10.72 mm, 1040 km;

In 2002, Kenkiyak-Atyrau Pipeline, ΦX65, 610 mm×7.1 mm, 86 km;

In 2003, Sudan Fula Field Crude oil Export pipeline, X65, Φ610mm, 7.1—11.9 mm, 725 km.

Table 5 and Table 6 give a brief introduction of the Chinese SSAW and LSAW pipe manufactures.

4 The prospect of the development of Chinese oil steel pipe

Facing the more and more strict technical requirements of the petroleum industry in oil pipe, China's steel pipe manufacturers and research institutes are developing new products now, which reveal the prosperity of the Chinese oil steel pipe manufacturing industry.

4.1 The prospect of oil well pipe

4.1.1 Drill strings steel pipe with high properties

The API standard drilling strings components cannot satisfy the more and more strict requirements in the changing servicing conditions. Now, many kinds of drill components are demanded, including the S135 drill pipe with the super-high strength (the precondition is assuring the toughness), the high toughness drill pipe which can satisfy the rule of "leaking before breaking" and can resist the friction heat cracking (increasing the toughness), the H_2S resistant drill pipe with high strength used in the deep well containing H_2S (increasing the capability to resist SSCC), high anti-twist drill pipe (combining with improving the connection structure design and improving the pipe body material).

In order to assure the efficiency and security during well drilling, the toughness of drill pipe must satisfy the rule of "leaking before breaking", namely the critical size of crack induced by fatigue or corrosion fatigue should greater than wall thickness of drill pipe. In terms of fracture mechanics, critical size of size is

proportional to $(KIC/\sigma_y)^2$. Thus the yield strength is higher (or pressure on drill pipe is greater), the higher toughness needed matching is.

4.1.2 Tubing and casing with high performance

The high performance casing and tubing needed by the deep well and the other strict servicing conditions: the super-high strength casing with its grade exceeding Q125 (improving toughness greatly, increasing strength and the same time).

Difficult points are as follows: (1) The toughness matching the casing with its grade exceeding Q125 is extremely high, known as the world-class puzzle; (2) The higher the strength of the steel is, it is the more difficult to improve SSCC resistance, it is the forbidden zone that the hardness exceeds HRC25.

The strength is inversely proportional to the plasticity and toughness of steel. For drill pipe with its grade above S135 and the casing with its grade above Q125, the toughness needed matching is extremely high, which has been a focus in recent years. The instructing technological file of British Energy Ministry stipulates that transverse minimum CVN for pressure pipe is calculated by the expression: CVN (J) $=\sigma_y$(MPa)/10.

Several years ago, during well completion of a deep well in the western China, V150 casing produced the spiral crack and caused this well to abandon, which led to lose more than one hundred million Yuan directly. Fig. 3 shows downhole photograph of the casing. According to failure analysis, the spiral crack was induced by high load (internal pressure) on potential spiral defect in steel pipe, which resulted from the hole-injection process.

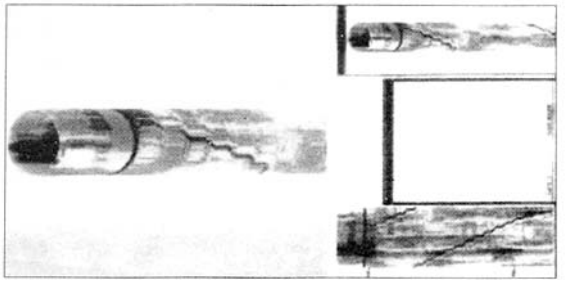

Fig. 3 The downhole photograph of the fracture casing in Keshen-1 well

Inherent defect or damage is unavoidable for the tubing and casing. Its critical value is relevant to $(KIC/\sigma_y)^2$, namely the casing is the higher in strength, and the higher the toughness needed matching is.

Tubular Goods Research Center of CNPC is now working on strength-toughness match of oil well pipes, including the way of improving toughness.

4.1.3 CO_2 resistant oil well pipes

In recent years, some oil and gas field in the harsh environment have been exploited worldwide. Foreign researchers have strengthened development of the corrosion-resistant oil well pipe, which can resist corrosion in the environment of CO_2 or CO_2 coexisting with H_2S, Cl^-, H_2O, etc. Research on CO_2 resistant oil well pipes has already been listed as "863" Plan in China.

API SPEC 5CT only requires 13Cr (L80-13Cr). But now every producer has developed its own non-API series for resisting CO_2. Take Kawasaki Steel for instance, its non-API series has 8 steel grades, namely KO-13Cr80, KO-13Cr85, KO-13Cr95, KO-13Cr110, KO-HP1-13Cr95, KO-HP1-13Cr110, KO-HP2-13Cr95 and KO-HP2-13Cr110, etc. Among them, the last 4 steel grades are called super 13Cr.

When CO_2 and H_2S were mixed up, H_2S content so small that that cannot arrive the critical point, 13Cr steel (include super 13Cr) cannot satisfy the demand for resisting corrosion, even the Cl^- content is high. The 22Cr duplex stainless steel (ASF2205) or 25Cr super duplex stainless steel is needed, and the higher Ni and Cr stainless steel or Ni based alloy which contains more than 20%Cr and 30%Ni is needed too.

The above types of steel is very expensive, so it can not be afforded for the low production fields, and that's why how to choose the CO_2 resistant oil well pipes, and how to use and develop the low price oil well pipe with CO_2 resistant capability have become the hot research subjects.

4.1.4 Coiled tubing

Coiled tubing units were used during work over and well completion. The technology of using coiled tubing units during drilling is a focus in recent years. Coiled tubing is a kind of steel pipe with good strength and toughness, which is stored on a reel and is mainly made up of ERW. Now seamless steel pipe used in coiled tubing is being developed and its material is being developed from carbon steel to low alloy steel (including quenched and tempered steel, titanium alloy, etc.). Research on coiled tubing used composite material is in progress now. Outer diameter of coiled tubing has changed from 1, 1-1/4, 1-1/2 and 1-3/4 inches at the end of the eighties to 2, 2-3/8, 3-1/2 inches now, which can meets slim-hole drilling. The yield strength of coiled tubing has increased from 492 MPa or 562 MPa to 703 MPa now. Coiled tubing must have good strength-toughness match so as to ensure high low-cycle fatigue life.

America Energy Ministry is devoted to developing coiled tubing-based microhole technology, which is planned for drilling 20000 shallower pool tests, 100 data monitor wells, 1000 exploration wells, 3000 reentry wells every year. 400000 wells wait for developing the new oil reservoir again at present in U. S. A. Drilling reentry wells costs at least 7500 million dollars every year. There is a wide prospect to apply coiled tubing-based microhole technology. By the end of 2003, using this technology, has drilled more than 7000 wells in the whole world. Canada accounts for 90% of total amount in the world.

The goal of applying coiled tubing-based microhole technology ($\leqslant 3\ 1/2''$) is to save 40%—50% of expenses than conventional drilling technology and can drill well depth maximum to 6000 feet. In West Texas, total cost of well drilling using conventional technology is 25—35 tens thousand dollars, that is only 15 tens thousand dollars when using coiled tubing-based microhole technology.

Producing and applying coiled tubing is still a complete blank in our country. Relevant research is to start now.

4.1.5 Expandable casing

Expandable-tubular technology is a new practical drilling technology in recent years. The expandable casing string is run in the hole on an inner-string with a launcher assembly containing the expansion cone. Fluid is pumped down the work string. The force of hydraulic pressure pushes the cone up the casing, thereby expanding the casing. Expandable Casing includes solid expandable casing and slotted one. The main purposes of solid expandable casing are as follows: thief zone sealing and high pressure water exclusion, crushed zone sealing, casing patch and perforating casing packer, the substitute for conventional liner hanger and liner hanger packer in order to maintain hole size. As a new completion technique to improve oil well production, slotted expandable casing is mainly used in crushed zone sealing and sand meshwork expansion.

Before the advent of expandable casing, operators had to use sections of progressively smaller-diameter pipe as they drilled deeper, resulting in a "telescoped" conduit. By using expandable-tubular technology during drilling, the size of the hole can be maintained and the target reached with minimal well tapering. The breakthrough of this industry meets urgent 21st-century challenges posed by drilling. Fig. 4 shows conventional design, casing design with nested expandable current capability, and the mono bore design (from left to right).

Solid expandable casing technology, estimated by Shell researchers, promises to significantly reduce the cost of drilling, which can decrease rig field by 75%, drilling fluid by 20%, drilling cuttings by 50%

and cement by 50%.

How to choose steel for expandable casing is one of the key technologies. Expandable casing is expanded in the hole, namely produces plastic deformation. Then it serves in the harsh environment, which must endure external force, internal pressure and corrosion induced by corrosion medium. Expandable casing processes adequate ability of plastic deformation. During the expansion process, its mechanical property and dimension precision should meet API standard or other relevant specification.

Research on expandable casing technology has lasted 3 years in China, as a whole still stayed in the laboratory.

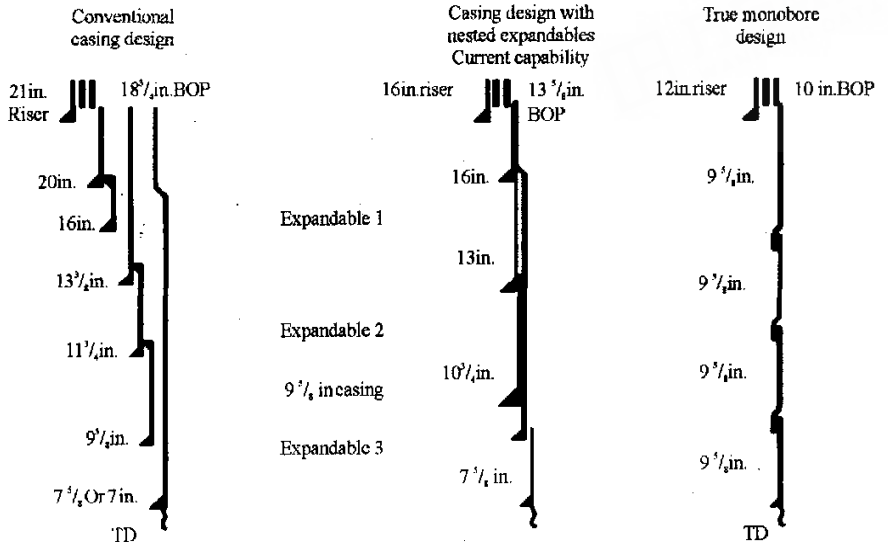

Fig. 4 Comparison of conventional casing design with expandable casing design

4.2 The prospect of the oil and gas transportation pipeline

At present, the challenge faced by the oil and gas pipeline industry is to build the gas pipeline with long distance, high pressure, and large flux in the harsh environment with cold weather, deep sea, desert and the other geological disaster. Hence, the following types of oil and gas transportation pipeline need to be developed.

4.2.1 Pipeline steel and pipeline (X80 and above it) with high strength

The general tendency for oil and gas transmission pipeline (especially gas pipeline) is to increase the strength of pipe continuously in order to reduce pipeline construction and running cost greatly. X80 is the highest grade that can be mass-produced in Japan, Europe, North America and that have been used normally in pipelines. X100 and X120 grade pipe steels are being developed and tested.

X70 grade pipe steel and operating pressure of 10 MPa are used for WEGTE Project. Currently, research on X80 application is in organization, and test and research on such higher-grade pipe steels will start, which is the to preparation for next international upgrade of pipe steel.

The world famous oil companies lead the development and application of X80 grade and higher grades pipe steel continuously. In 1996 EXXON Mobil signed contracts with Nippon and Smitomo separately to develop X120 grade pipe steel, which was complete in 2001, and it is announced that X120 is being accounted to use in long distance pipeline. Cooperated with several iron and steel corporations and pipe making factories, BP developed X100 grade UOE pipe. In order to evaluate its fracture arrest ability full-scale burst

tests have been done many times. Through comparing tests between X100, X80, X70 produced by Europipe, Italy SNAM got results that the spot welding of X80 can used the process similar to that of X70 welding one, but it's different for X100, satisfied result can be obtained by taking proper measures. Norway STATOLL studied the feasibility of using X80 grade steel made by Nippon, Smitomo, NKK, Kwasaki and Europipe for submarine pipe, which is focused on the weld ability, matching of welding materials, the toughness and deformability of welded joint, and got satisfied results.

TCPL of Trans Canada is pioneer to propel higher grade steel, the recent developments are: TCPL started to use X80 in pipeline network during 1994 to 1995 and built a 30 km long test pipeline; by now, there are about 400 km X80 grade pipeline in its pipeline network; X80 grade steel pipes have already been successfully used in aver frozen areas in North Alberta; In 2002, TCPL built a testing pipeline of X100 with diameter of 1219 mm, thickness of 14.3 mm; in order to test the fracture arrest property, two times full scale burst test of X100 grade pipe with diameter of 36″ were conducted, and the test results are in good agreement with the predicted value.

4.2.2 Pipeline steel and pipeline used under the low temperature environment

The lowest running temperature of oil and gas transmission pipeline buried underground is generally 0℃, but for beard pipelines (such as pipelines in station and suspended pipelines) the environment temperature should be taken into account to ensure the running safety. Under this circumstance, the ductile-brittle transition temperature of pipe steel should be lower than the local limit low temperature, and the pipe steels should have enough toughness at that temperature, which is quite difficult to high strength pipe steels.

4.2.3 Pipeline steel and pipeline with suitable cracking controlled performance

Accordingly, because of the lower pressure decreasing speed (V_d) of gas and the higher cracking speed of pipe (crack propagate speed), V_m is bigger or equal to V_d, crack will propagate through long distance and conduct disastrous consequence. Increasing the toughness of pipe can decrease crack propagate speed and make $V_m < V_d$, so the crack is arrested.

The toughness of steel pipe must be higher if the transmitting is rich of C2—C5, because the more content of C2—C5, namely the more higher the heat content, the lower the pressure decreasing speed.

Though it has been twenty-six years since the development of X80 grade steel, it hasn't used in gas pipelines in large scale. One of the important reasons is that the problems about fracture control haven't solved. Ductile fracture arrest of line pipe is related to CVN, which is calculated through semi-empirical crack arrest equations, like Battelle equation, and modified with full-scale burst test. A lot of full-scale test data have been accumulated for steels under X70 grade, so the prediction accuracy is accepted, but the testing data of X80 grade steel is quite few and the prediction reliability is doubt.

Full-scale burst tests have been conducted for X80 grade natural gas transmission pipeline with diameter of 48 in, wall thickness of 17 mm. It is surprised that crack propagation took place in a pipe with high impact energy of 221 J, however the calculated fracture toughness is only 125 J.

Fracture arrest toughness have been predicted by Japan Smitomo about rich gas transmission pipe with content of 89.5 percent methane and 6.5 percent ethane, it is much higher than 500 J for X80 grade steel pipe working at pressure of 10 MPa, obviously it reached the limit of contemporary metallurgy techniques.

It can be seen from this Figure that the required fracture arrest toughness will decrease to about 50 J, if the transmission pressure is increased to 20 MPa.

But this research result also shows that the required fracture arrest toughness will decrease to about 50 J, if the transmission pressure is increased to 20 MPa.

It's considered to use more higher grade steel than X80 grade and use 300 MPa or much higher transmission pressure for rich gas transmission, and it is advised to use double layer pipe of high strength steel pipe and lass fiber composite material pipe.

4.2.4 Pipeline steel and pipeline with the HIC resistant capability

SSCC and HIC are main fracture modes of natural gas transmission pipeline with H_2S content. SSCC and HIC resistant pipeline steel has been systematized abroad. Occurrence of SSCC and HIC and the severity level are determined by H_2S differential in transmitted gas media. Requirement of SSCC and HIC resistance must be put forward to pipe material when PH_2S is greater than 300 Pa, and H_2S content should be reduced to very low level to meet with the demands of $p(H_2S)\leqslant 300$ Pa, for example, H_2S content should be reduced to lower than 0.003 percent if $P_0=10$ MPa. So the demand for HIC resistant steel is in urgent, for instance the sales volume of HIC resistant oil and gas transmission pipe has been more than 30 percent in Europe.

It is X65 grade HIC resistant pipe steel that can be mass supplied abroad. X70 grade HIC resistant steel pipe has been developed successfully and used for a pipeline in Mexico. Research and development of SSCC and HIC resistant pipe steel is just started and should be speeded up in China.

Measures of improving SSCC and HIC resistance of pipe materials are as follows: (1) Use refined materials and process of high effective pretreatment of liquid iron and composite refine outside furnace to increase the purity of steel to $S\leqslant 0.001\%$, $P\leqslant 0.010\%$, $[O]\leqslant 20$ ppm, $[H]\leqslant 1.3$ ppm. NKK stipulated that the total content of ten kinds of elements, namely S, P, N, H, O, Pb, As, Sb, Bi, should be less than 80 ppm. (2) Increase the homogeneity of chemical compositions and microstructures. Use processes of calcium treatment, electric-magnetic stirring of liquid iron and electric-magnetic stirring in the course of continuous casting, soft reduction in the course of continuous casting, stages controlled rolling and accelerated cooling, restricting band microstructures, as well as decreasing sulphur content. (3) Refine grains. Concentrate on micro alloying and controlled rolling process. (4) Reduce carbon content (generally less or equal to 0.06 percent), control Mn content and add chemical composition of Cu.

4.2.5 Pipeline steel and pipeline with the CO_2 resistant capability

In oil field, research about CO_2 corrosion and protection is not ripe, but the corrosion results are very serious. CO_2 corrosion should be taken seriously for pipes used as internal collection and transmission pipe from wells to treating factories (without dehydration, desulphation and decarbonization) and for gas transmission pipelines that didn't decarbonized ideally. Under circumstance of $p(CO_2)>0.021$ MPa, Cr13 Martensite stainless steel, Cr22 dual-phase stainless steel, Cr25 super dual-phase stainless steel, Cr-Ni stainless steel with Ni content much high than 35 percent, even Ni based alloy can be used separately according to $p(CO_2)$, $p(H_2S)$ and Cl^- content. Comparing with ordinary line pipe steel, stainless steel is more expensive. So composite steel pipes lined with just mentioned stainless steels are preferred to decrease the cost. In China, many gas fields produce gas accompanied with CO_2, but the CO_2 corrosion resistant pipe steels are in luck. So attention should be paid to the selection for pipe in CO_2 environments.

4.2.6 Pipeline steel and pipeline with the high deformability

Pipelines should have higher large deformation resistance to passing through larger areas. Large deformation resistant pipeline steel has been developed abroad.

The large deformation resistant pipe steel has higher stain-strength ratio, larger uniform plastic elongation, lower ratio of yield strength to ultimate strength, and no Lauders elongation.

Since China has more earthquakes and more geology disasters (such as land slide and mud-rock flow), the development of large deformation resistant pipe steel is quite necessary. Relevant research is ongoing in

Tubular Goods Research Center of CNPC.

4.2.7 Complex pipe of steel and fiberglass

Along with the continuous increasing of transmission pressure of pipeline, the fracture arrest requirement is in need urgently, which has exceeded the limit of metallurgy techniques. In order to solve this problem, composite strengthened pipes (CRLP) have been studied and developed abroad. It is steel/glass fiber composite pipe that combine the strength of steel and the fracture arrest superiority of glass fiber, decrease material cost, mounting cost and welding cost in pipeline project, substitute conventional coating.

Study and development of steel/glass fiber composite pipe can promote the increase of the safety and reliability of pipeline in addition to the economic benefit of pipeline project.

5 Conclusion

The oil steel pipe production develops with a high speed. The oil well pipe and the oil & gas transportation pipe (include steel plate and coil) have already achieved a high level with a high self-support ratio. Many new types have been developed, almost covering all API grades and dimensions. All the iron & steel corporations, pipe manufacturing corporations and research institutes are making their efforts to develop more and more steel pipe types to offer better service to consumers.

References

[1] Huang Z Q, Li P Q, Liu T M, et al. The requirements and countermeasures on oil well pipe and line pipe by oil industry development[J]. OCTG & Line Pipe, 1998, 6:1—10.

[2] Li H L. The development aspect of oil and gas transportation pipeline and the discussion on domestic production [J]. OCTG & Line Pipe. 1996,5(2):1—13.