Thermal Recovery Status and Development Prospect for Heavy Oil in China
Liu Wenzhang Research Institute of Petroleum Exploration and Development, CNPC, China

Abstract
In China, the technology of thermal oil recovery developed late but fast. In the past five years, the thermal oil recovery technology in China has continuously made progress. Cyclic steam stimulation is still the major technology that is used to recover heavy oils. For each different reservoir type of heavy oils and extra heavy oils, the development area by using cyclic steam stimulation has been expanded to a large extent. The process technologies of steam injection have also made new improvements. In 1993, the annual thermal oil production exceeded 1000×10⁴t. In 1997, this number increased to 1100×10⁴t. The heavy oil reserves which have been put into production by steam injection exceed 800 million tons (8×10⁸t). The total number of production wells exceeds 8,000. Some shallow heavy oil reservoirs in north-western parts of China have been converted from cyclic steam stimulation into steam drive. In eastern China, the steam drive pilots of deep heavy oil reservoirs are in progress. Several pilots of thermal recovery by using horizontal wells in extra and super extra heavy oil reservoirs are in progress.

Introduction
The onshore heavy crude and tar sands in China are distributed widely and are 20% of China’s total petroleum resource. Up to now, more than 70 heavy oil fields have been found in 12 basins where 1.2 billion m³ of OOIP exist (see Figure 1).

Since 1982, the thermal oil recovery technology has developed very fast. Cyclic steam stimulation has become the major technology of heavy oil recovery. In China, the 1985 total thermal heavy oil production was 75×10⁴t. This increased to 737×10⁴t in 1990. By 1993, 1000×10⁴t were thermally produced. And has been maintained at 1100×10⁴t through 1997. The total well number has been up to 9,000. The national heavy oil production, including the conventional cold oil production, is maintained at 1300×10⁴t which is 9% of the total onshore oil production (Table 1 and Figure 2).

The national heavy oil production by thermal recovery is mainly from four areas: Liaohe, Xinjiang, Shengli, and Henan. The producing heavy oil reserve exceeds 8×10⁸t.

During the last decade, cyclic steam stimulation technology in deep wells has improved and become mature. Secondary thermal recovery technology, including steamflooding, is developing and improving. Oil production from steam drive was 48.7×10⁴t in 1995 and 84×10⁴t in 1997. In the future, steam drive technology will be developed as fast as possible. Several field tests show that various horizontal well technologies in thermal oil recovery will become effective methods to develop China’s extra and super heavy oil.

Geological Characteristics and Types of Heavy Oil Reservoirs
The heavy oil reservoirs have the geological characteristics of terrestrial deposit which are as follows:

1. Heavy crude has the characteristics of high resin content, low asphaltene content, and high viscosity with large variation.

Most heavy oils belong to the class of low mature oil but some of them are mature and high mature oil. A few of them are from immature source rock. Compared with the international classification criterion of heavy oils, oil viscosity varies greatly and its relative density varies a little. I put forward a classification criterion of heavy oils in order to select the suitable development scheme, in which the heavy oils are divided into three types including conventional heavy oil, extra heavy oil, and super heavy oil (Table 2).

2. The reservoir depth varies greatly. In Eastern China, many reservoirs that are produced by thermal means are more than 800m deep and some of them are up to 1700m. In Western China, the heavy oils in Karamay are distributed widely and are shallow in depth. A heavy oil reservoir with the depth of 2700–3200m was discovered in Tuha area of Xinjiang region.

3. The reservoirs of heavy oil mainly consist of coarse clastic rock. There are many sand body types which have high porosity and permeability but low oil saturation.

4. The geological conditions of heavy oil reservoirs are complicated and there are many reservoir types.
There are about ten types of reservoirs which have been produced by thermal recovery:

- Deep massive heavy oil reservoir with a gas cap, such as the Gaosheng heavy oil reservoir in Liaohe area (Figure 3). There is a gas cap in the top sand and a bottom water zone in the reservoir.
- Massive heavy oil reservoir with active edge and bottom water, such as the heavy oil reservoir of Shu 175 block in Liaohe area and the Shanjiasi heavy oil reservoir of Shan 2 block in Shengli area (Figure 4).
- Thick interbedded heavy oil reservoirs with edge water, such as the heavy oil reservoir of Jin 45 block in Liaohe area.
- Thin interbedded heavy oil reservoirs, such as the heavy oil reservoir of Du 66 block in Liaohe area.
- Deep interbedded heavy oil reservoirs with intermediate thickness, such as the heavy oil reservoir of Qi 40 block in Liaohe area.
- Glutenite extra heavy oil reservoir, such as the Le’ an heavy oil reservoir in Shengli area.
- Shallow bedded heavy oil reservoir with individual layers, such as the heavy oil reservoirs of No. 9 block in Karamay oil field.
- Shallow and thin heavy oil reservoir, such as the Jin-g lou heavy oil reservoir in Henan area.
- Shallow bedded super heavy oil reservoir, such as the heavy oil reservoir of Fengcheng district in Karamay area.
- Deep massive super heavy oil reservoir, such as the Xinglongtai heavy oil reservoir of Du 84 block in Liaohe area.

The first eight types of heavy oil reservoirs have been successfully put into production by steam injection. The last two types were not successful by conventional thermal methods, but thermal recovery with horizontal wells are successful.

**Cyclic Steam Stimulation**

Up to now, cyclic steam stimulation, CSS, has been the major method to develop heavy oil reserves in China. Its wide spread application in China results from three reasons:

1. Small investment, high rate of oil production, good economic benefit.
2. Even if the reservoir is deep (such as 1700m), the process technologies of thermal recovery are mature and complete.
3. Cyclic steam is suitable for various types of heavy oil reservoirs.

CSS is still the primary oil recovery by natural energy under the conditions of reducing the oil viscosity through heating the heavy oil reservoir. Therefore its oil recovery factor is generally about 15% OOIP, and the factors of some reservoirs can be up to 20% OOIP.

**Table 3** shows the production performance of each cycle for an individual well in Gaosheng oil field in Liaohe area. The production performance of Shanjiasi oil field in Shengli area is illustrated in **Table 4**. Since 1993, the number of CSS wells which have finished more than 5 cycles has been 36.1% of the total number of CSS wells in China. From 1986 to 1993, the national average oil production per well cycle and annual OSR of CSS are illustrated in **Figure 5**.

Although new reservoirs and new wells are put into production every year (**Table 1** and **Figure 5**) the national oil production by thermal recovery increases and, the average oil production of each cycle and annual oil steam ratio, OSR, decrease every year. For a fixed reservoir or block, with increasing steam cycles, the production time of each cycle decreases, as does oil production and the OSR. So, economic benefit gradually becomes poor. The number of steam stimulation cycles which are economical and effective is 6–7 and should not be greater than 10 (**Tables 3 and 4**).

In steam stimulation, the major advances in recent years are as follows:

- Develop most of the technology for improving CSS.
- Infill drilling to prolong the production period.
- Expansion of steam drive pilots and the area developed.
- Explore and develop new heavy oil reservoirs.

**Steam Drive and Other Technologies of Thermal Oil Recovery**

1. **Challenge and the concept of secondary thermal recovery**

Up to now, most heavy oil reservoirs and blocks which have been put into production in China are in the middle or late stage of CSS. Even if many reservoirs and blocks can continue to be developed by infill drilling, the increase in recovery factor is limited, only 5 to 8%, and the cumulative oil recovery factor from CSS will not be greater than 20%.

The Gaosheng oil field in Liaohe area is an example. First, quadrangular well patterns were used in which well spacing was 210m. When CSS terminated, the oil recovery factor was 6.2% and interim OSR was 0.77. The reservoir pressure decreased from 16MPa to 12MPa. Second, infill drilling reduced well spacing to 150m. When CSS terminated, oil recovery factor was 8.5% and interim OSR was 0.66. The reservoir pressure decreased to 7MPa. Third, well spacing was reduced to 105m. From November 1994, it is predicted that CSS will produce 5 cycles and the oil recovery factor will increase 5.6%. The interim OSR will be 0.54. So the cumulative oil recovery will be 20.4% (**Table 5**). Although CSS has not terminated, the reservoir pressure has decreased to less than
5MPa. Therefore the chance of converting to steam drive is drawing near.

Most of the heavy oil reservoirs must be developed by some other methods after CSS. In recent years, test results of more than ten steam drive pilots show that steam flood of shallow heavy oil reservoirs is successful. An example is the heavy oil reservoirs of No. 9 block in Karamay area. For the deep heavy oil reservoirs in Eastern China, steam drive results from the heavy oil reservoirs of Shu 175 block in Liaohe area and Le’an district in Shengli area are inspiring. But many reservoirs have complicated geological conditions, and new problems which do not favor steam drive appear during CSS. Therefore it is difficult to expand steam drive development in these reservoirs.

Based on my studies, most heavy oil reservoirs and blocks can be converted to secondary thermal recovery methods. The secondary thermal recovery methods include steam drive, high temperature hot water flooding, foam drive with hot water and nitrogen, hot water flooding with surfactant, or some other multiple drive technology.

The reason for implementing the secondary thermal oil recovery is as follows:

- After steam stimulation, recovery factors are low and the remaining oil reserves are still high. The average oil saturation is greater than 50%. It is predicted that the recovery factors can be increased by 20 to 30%.
- The technologies of steam drive and hot water flooding in deep heavy oil reservoirs are mature. The matched technologies of high temperature surfactant injection are also mature and new technologies are being developed.
- Although new investment is necessary in secondary thermal recovery, it is much lower than that of the exploration or development of new reservoirs. The economic benefit of secondary thermal oil recovery is optimistic.

2. **Steam drive**

- In recent years, the key technologies which influenced the success or failure of steam drive, such as the heat insulation technology for steam injection into deep wells, the technology of improving steam conformance, profile control technology by nitrogen foam, and energy-saving technology, have been developed. Thus they provide favorable conditions for expanding development of steam drive.
- Steam drive experience has been obtained from steam drive pilots of different reservoirs, such as: the performance optimization of steam drive in No. 9 block of Karamay oil field, the edge water propagation control of the steam drive in She 175 block of Leah area, and steam channeling control by nitrogen foam injection.
- It is predicted that more than 50% of the produced heavy oil reservoirs currently produced by steam injection can be converted to steam drive.
- Most of the reservoirs or blocks developed by steam injection have reduced well spacing by infill drilling. This provides a good condition for steam drive well patterns.

3. **Hot water drive**

For the conventional heavy oil reservoirs or blocks where the benefit of steam drive is poor, high temperature hot water drive or low quality steam drive can be used. Figures 6 and 7 show the results of oil laboratory displacement efficiency experiments from steam drive and hot water drive displacements under different temperatures for the heavy oil reservoirs of Du 66 block and Gaosheng oil field in Liaohe area. Their dead oil viscosity at reservoir temperature is $10^4 \text{mPa.s}$ and $1000 \text{mPa.s}$, respectively.

4. **Foam drive with hot water and nitrogen**

The test results from laboratory and the field indicate that for conventional heavy oil reservoirs, foam drive with hot water and nitrogen can control viscous fingering, increase sweep efficiency, and oil drive efficiency. For example, the heavy oil reservoir of Jin 45 block in Liaohe area was converted to conventional water drive from CSS but water channeling was very serious. The experimental results of physical laboratory models under different drive schemes are illustrated in Table 6 and Figure 8. Up to the end of 1997, the foam drive test in an inverted nine-spot pattern shows that the increase of oil production was 9540t. It is predicted that the oil recovery factor will be 10% higher than that of the water drive.

5. **Hot water surfactant drive**

For $S_{1+2}$ reservoir of Leng 43 block in Liaohe area, the dead oil viscosity at $60^\circ \text{C}$, $120^\circ \text{C}$, and $200^\circ \text{C}$ is $2000 \text{mPa.s}$, $85 \text{mPa.s}$, and $12 \text{mPa.s}$, respectively. Physical model experimental results indicates that the oil displacement efficiency improved when high-temperature tolerant surfactant is added to the hot water drive (Figure 9). It is clear that this method has some development prospects.

**Thermal Recovery of Extra and Super Heavy Oil by Horizontal Well Technology**

From 1988 to 1994, development tests indicate that recovering extra and super heavy oils in China by vertical wells yielded poor economic return because of low oil production of individual wells, low production per cycle and low oil-steam ratio.

In the last 5 years, studies and field tests of recovering super heavy oils by horizontal wells have developed fast. The steam stimulation technology of horizontal wells in Le’an super heavy oil reservoir has been successful. Up to October
1997, 32 horizontal wells have been put into production and
the oil production per cycle is 3–4 times higher than that of
vertical wells. Cumulative oil production is 44.4×10^4t and the
results are good.

For the shallow super heavy oil reservoir (170–200m in
depth) of No. 8 block in Karamay area, 3 of 4 horizontal wells
drilled in 1997 were put into production and their oil produc-
tion rate was 5–8 times higher than that of vertical wells. The
average oil production rate of individual wells was above 10t/
d.

For the super heavy oil reservoir of Du 84 block in Liaohe
area, the SAGD technology was used and a pair of parallel
horizontal wells were drilled. Up to the end of 1997, the pre-
heating period has been completed. The cumulative oil pro-
cduction in 4 months was about 2500t which was 20t/d on
average. The preproduction period of depressurization began
recently. It is predicted that the total production time is 7 years
and the cumulative oil production will be 15×10^4t and cumu-
ulative OSR of 0.27.

Based on the research done at RIPED, recovery of extra
and super heavy oil in China by thermal recovery technologies
in horizontal wells holds great potential in the future.

**Thermal EOR Engineering**

After more than ten years research and development, thermal
recovery engineering and production technology have
matured and meet the needs of modern thermal oil recovery in
China. Steam injection for deep, multi-zone and very hetero-
geneous heavy oil reservoirs has made great advances.

1. **Heat insulation technology in deep well bore**
   Highly efficient insulating tubing, high temperature-resis-
tance packers and nitrogen injection through the annulus
are widely used. Steam injection in deep well bore is suc-
cessful.

2. **Drilling and completion engineering of thermal horizon-
tal wells**
   The experience of drilling thermal horizontal wells is
spreading in China. This includes parallel horizontal
wells of SAGD, horizontal wells with long horizontal
intervals, and deflecting - horizontal wells at shallow
depth. The drilling cost per meter is decreasing.

3. **Sand prevention of producers**
   There are more than ten sand prevention methods devel-
oped ranging from initial open hole completion with
wire-wrapped screen and gravel pack in early days to var-
ious inside-casing mechanical sand control methods and
high-temperature chemical sand control methods in
recent days.

4. **Mechanical oil recovery**
   Artificial lift technologies with sucker rod pumps suitable
for thermal recovery have merged into an integrated pack-
age. Long stroke sucker rod pumps and well pumping
units have the production capacity of 100 to 300m^3/d per
well, there are various multifunctional oil well pumps.

5. **Oil viscosity reduction in well bore**
   In recent years, the heating technology by hot fluid and
electric cable in hollow sucker rods, and well bore heat-
ing in hollow oil well pumps are used to reduce the oil
viscosity in cold production and cyclic steam simulated
heavy oils. Injection of chemical viscosity-reducing
agents in the well bore are used extensively. All the mea-
sures help to increase oil production.

6. **Performance monitoring of producers and reservoirs**
   A four-parameter (steam profile, temperature, pressure,
and steam quality) down hole measuring instrument,
made in China, is used extensively. It can resist a temper-
ored of 350°C and the pressure of 22MPa.

   Monitoring technology of thermal recovery performance
by observation well or production well has been success-
fully applied.

   Application of chemical and radioactive tracers and the
monitoring technology of fine 3-D seismic has also pro-
duced good test results.

7. **Separate zone steam injection by multiple packers**
   Multiple steam injection packer technology can greatly
improve the steam injection profile. It was applied in
shallow wells of Karamay oil field, and deep wells of
Liaohe and Shengli oil fields. Several hundred steam
stimulation cycles in many wells have been conducted
successfully.

8. **Profile control technology in injection wells by high tem-
perature foam agent**
   Various high temperature-resistant foam agents, made in
China, have been used extensively in steam simulation
wells and injectors of steam drive in several oil fields.

   They have produced good results.

9. **Increasing oil production by chemicals**
   In recent years, various chemicals were used extensively
and produced good results. These include: plugging
agents that are high temperature-resistant and can control
steam channeling; chemical agents which can release bot-
ttom-hole plugging; antiswelling agents, cleanup additives
for steam stimulation wells, and viscosity-reducing
agents.

10. **Steam generators and surface steam injection system**
   There are three Chinese factories that manufacture steam
generators. By the end of 1997, more than 400 steam gen-
erators were in use in China. Their quality and technical
features meet the need of steam injection. The steam gen-
erators have the following capacities: 6 t/h, 9.2 t/h, 11.5 t/
h, and 23t/h; they are designed for three working pres-
sures: 10MPa, 17.8MPa, and 22.0MPa.
Conclusions of Technology Development Prospects of Heavy Oil Recovery in China

In the future, heavy oil recovery technologies will continue to be developed and mature in China. Onshore heavy oil production will be maintained at the current level.

1. The development schemes of conventional heavy oil reservoirs will be converted from CSS to secondary thermal recovery. Oil recovery will be greatly improved.

2. Various horizontal wells will be used to increase oil production in extra and super heavy oil reservoirs.

3. New technologies will be applied to improve oil recovery and economic benefit in complicated heavy oil reservoirs such as: reservoirs with active edge and bottom water, thin interbedded heavy oil reservoirs, and deep heavy oil reservoirs (about 3000m in depth). It is still difficult to recover heavy oil from these kinds of reservoirs under current conditions.

References


Table 1: Thermal Oil Production of China in Past Years

<table>
<thead>
<tr>
<th>Year</th>
<th>Steam Stimulation Well Times</th>
<th>Heavy Oil Production (10^4 t)</th>
<th>Thermal Oil Production (10^4 t)</th>
<th>Annual OSR (tA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>229</td>
<td>105.8</td>
<td>75</td>
<td>1.36</td>
</tr>
<tr>
<td>1986</td>
<td>425</td>
<td>295</td>
<td>150</td>
<td>1.67</td>
</tr>
<tr>
<td>1987</td>
<td>1104</td>
<td>407.7</td>
<td>296.7</td>
<td>1.27</td>
</tr>
<tr>
<td>1988</td>
<td>2032</td>
<td>532.5</td>
<td>455.8</td>
<td>0.93</td>
</tr>
<tr>
<td>1989</td>
<td>3164</td>
<td>671.5</td>
<td>596.5</td>
<td>0.72</td>
</tr>
<tr>
<td>1990</td>
<td>4358</td>
<td>839.9</td>
<td>733.4</td>
<td>0.68</td>
</tr>
<tr>
<td>1991</td>
<td>6775</td>
<td>941.2</td>
<td>837.7</td>
<td>0.62</td>
</tr>
<tr>
<td>1992</td>
<td>7220</td>
<td>1056.1</td>
<td>958</td>
<td>0.58</td>
</tr>
<tr>
<td>1993</td>
<td>9229</td>
<td>1189.2</td>
<td>1066.2</td>
<td>0.50</td>
</tr>
<tr>
<td>1994</td>
<td>8142</td>
<td>1298</td>
<td>1100.3</td>
<td>0.61</td>
</tr>
<tr>
<td>1995</td>
<td>8808</td>
<td>1300</td>
<td>1096</td>
<td>0.41</td>
</tr>
<tr>
<td>1996</td>
<td>9000</td>
<td>1310</td>
<td></td>
<td>0.36</td>
</tr>
</tbody>
</table>

Note: The heavy oil production includes thermal recovery oil production and conventional cold oil production in part, but it does not include the heavy oil production by water injection.

Table 2: Classification Criterion of Heavy Oils China
<table>
<thead>
<tr>
<th>Cycle</th>
<th>Number of Ending Producers</th>
<th>Steam Injection (t)</th>
<th>Intensity of Steam Injection (t/m)</th>
<th>Production Time (d)</th>
<th>Cyclic Oil Production (t)</th>
<th>Oil Production Rate (t/d)</th>
<th>Cyclic Water Production (t)</th>
<th>OSR</th>
<th>Back Water Productivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>425</td>
<td>2257</td>
<td>56</td>
<td>198</td>
<td>3266</td>
<td>16.5</td>
<td>111</td>
<td>1.45</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>316</td>
<td>3035</td>
<td>74</td>
<td>157</td>
<td>2307</td>
<td>14.7</td>
<td>163</td>
<td>0.76</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>217</td>
<td>3567</td>
<td>87</td>
<td>138</td>
<td>1902</td>
<td>13.8</td>
<td>254</td>
<td>0.53</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>112</td>
<td>3906</td>
<td>97</td>
<td>131</td>
<td>1491</td>
<td>11.4</td>
<td>362</td>
<td>0.38</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>62</td>
<td>4100</td>
<td>100</td>
<td>78</td>
<td>956</td>
<td>12.3</td>
<td>407</td>
<td>0.23</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>29</td>
<td>4256</td>
<td>104</td>
<td>102</td>
<td>997</td>
<td>9.8</td>
<td>389</td>
<td>0.23</td>
<td>9</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>3984</td>
<td>96</td>
<td>45</td>
<td>667</td>
<td>14.8</td>
<td>475</td>
<td>0.17</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>4668</td>
<td>131</td>
<td>65</td>
<td>481</td>
<td>7.4</td>
<td>583</td>
<td>0.10</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 3: Production Performance of Each Steam Stimulation Cycle in Gaosheng oil Field

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Number of Ending Producers</th>
<th>Average Oil Sand Thickness (m)</th>
<th>Average Perforation Thickness (m)</th>
<th>Average Steam Injection (t)</th>
<th>Intensity of Steam Injection (t/m)</th>
<th>Production Time (d)</th>
<th>Cyclic Oil Production (t)</th>
<th>Oil Production Rate (t/d)</th>
<th>Cyclic Water Production (t)</th>
<th>Cyclic Water Cut (%)</th>
<th>Cyclic OSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>483</td>
<td>31.3</td>
<td>16.8</td>
<td>3373</td>
<td>107.9</td>
<td>160</td>
<td>4229</td>
<td>26.5</td>
<td>7003</td>
<td>62.3</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>411</td>
<td>31.2</td>
<td>16.7</td>
<td>3931</td>
<td>125.9</td>
<td>222</td>
<td>4467</td>
<td>20.1</td>
<td>7459</td>
<td>62.5</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>322</td>
<td>31.8</td>
<td>17.0</td>
<td>4090</td>
<td>128.5</td>
<td>204</td>
<td>3369</td>
<td>16.5</td>
<td>7303</td>
<td>68.4</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>270</td>
<td>33.0</td>
<td>17.3</td>
<td>4090</td>
<td>123.9</td>
<td>192</td>
<td>2524</td>
<td>13.1</td>
<td>7336</td>
<td>74.4</td>
<td>0.6</td>
</tr>
<tr>
<td>5</td>
<td>206</td>
<td>32.1</td>
<td>17.1</td>
<td>4169</td>
<td>129.9</td>
<td>177</td>
<td>2066</td>
<td>11.7</td>
<td>7193</td>
<td>77.7</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>142</td>
<td>32.7</td>
<td>17.3</td>
<td>4143</td>
<td>126.7</td>
<td>160</td>
<td>1947</td>
<td>12.2</td>
<td>6988</td>
<td>78.2</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>92</td>
<td>32.3</td>
<td>16.6</td>
<td>4162</td>
<td>128.9</td>
<td>148</td>
<td>1669</td>
<td>11.3</td>
<td>5853</td>
<td>77.8</td>
<td>0.4</td>
</tr>
<tr>
<td>8</td>
<td>59</td>
<td>32.5</td>
<td>17.7</td>
<td>4274</td>
<td>131.6</td>
<td>149</td>
<td>1690</td>
<td>11.4</td>
<td>6079</td>
<td>78.3</td>
<td>0.4</td>
</tr>
<tr>
<td>9</td>
<td>34</td>
<td>33.5</td>
<td>18.6</td>
<td>4141</td>
<td>123.5</td>
<td>116</td>
<td>1422</td>
<td>12.2</td>
<td>4292</td>
<td>75.1</td>
<td>0.3</td>
</tr>
<tr>
<td>10</td>
<td>19</td>
<td>35.0</td>
<td>18.2</td>
<td>4329</td>
<td>123.7</td>
<td>120</td>
<td>1297</td>
<td>10.8</td>
<td>4954</td>
<td>79.3</td>
<td>0.3</td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>34.5</td>
<td>17.8</td>
<td>3966</td>
<td>114.9</td>
<td>155</td>
<td>849</td>
<td>5.5</td>
<td>7130</td>
<td>89.4</td>
<td>0.2</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>33.0</td>
<td>19.0</td>
<td>3949</td>
<td>119.5</td>
<td>92</td>
<td>775</td>
<td>8.4</td>
<td>3194</td>
<td>80.5</td>
<td>0.2</td>
</tr>
<tr>
<td>13</td>
<td>4</td>
<td>33.0</td>
<td>19.0</td>
<td>4089</td>
<td>123.5</td>
<td>140</td>
<td>681</td>
<td>-</td>
<td>7952</td>
<td>92.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Table 4: Production Performance of Each Steam Simulation Cycle in Shanjiasi Oil Field
### Table 5: Comparison of Steam Stimulation Results Under Different Well Spacing in Gaosheng Oil Field

<table>
<thead>
<tr>
<th>Well Spacing (m)</th>
<th>Production Time (d)</th>
<th>Oil Production (t)</th>
<th>Steam Injection (t)</th>
<th>Oil Recovery (%)</th>
<th>OSR</th>
<th>Commissioning Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>1750</td>
<td>33500</td>
<td>43470</td>
<td>6.3</td>
<td>0.77</td>
<td>Nov. 1988 - Nov. 1990</td>
</tr>
<tr>
<td>150</td>
<td>1380</td>
<td>46070</td>
<td>70080</td>
<td>8.5</td>
<td>0.66</td>
<td>Nov. 1992 - Nov. 1994</td>
</tr>
<tr>
<td>105</td>
<td>1550</td>
<td>30010</td>
<td>55730</td>
<td>5.6</td>
<td>0.54</td>
<td>From Nov. 1994</td>
</tr>
<tr>
<td>Total</td>
<td>4690</td>
<td>109680</td>
<td>169280</td>
<td>20.4</td>
<td>0.65</td>
<td></td>
</tr>
</tbody>
</table>

Note: 1. Infill drilling is based on the area and oil reserve of individual well pattern with well spacing of 210m
2. The data for well spacing of 210m and 150m are production data of the field, but include the prediction values for well spacing of 105m

### Table 6: Displacement Experiment Results of Different Displacement Type for the Heavy Oil Reservoir of Jin 45 Block

<table>
<thead>
<tr>
<th>Oil Displacement Fluid</th>
<th>Ultimate Displacement Efficiency (%)</th>
<th>Difference of Displacement Efficiency Compared with Water Drive (%)</th>
<th>Ultimate Residual Oil Saturation</th>
<th>Difference of Residual Oil Saturation Compared with Water Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>14.8</td>
<td></td>
<td>0.554</td>
<td></td>
</tr>
<tr>
<td>Foam</td>
<td>60.1</td>
<td>45.3</td>
<td>0.259</td>
<td>-0.295</td>
</tr>
<tr>
<td>Water and Nitrogen</td>
<td>47.5</td>
<td>32.7</td>
<td>0.341</td>
<td>-0.212</td>
</tr>
<tr>
<td>Foam and Nitrogen</td>
<td>71</td>
<td>56.2</td>
<td>0.188</td>
<td>-3.66</td>
</tr>
</tbody>
</table>

Table 6: Displacement Experiment Results of Different Displacement Type for the Heavy Oil Reservoir of Jin 45 Block
Figure 1: The Distribution Map of China Heavy Oil Reserves

Figure 2: The Increase Curve of Heavy Oil Production in China
Figure 3: The Geological Structure and Reservoir Profile of Gaosheng Oil Field

Figure 4: The Cross Profile and Elevation Profile of the Heavy Oil Reservoir in Shan 2 Block
Figure 5: Production Performance of Steam Stimulation in China in Past Years

Figure 6: The Experiment Curve of Displacement Efficient of Du 66 Block in Liaohe Area
Figure 7: Displacement Efficient Curves of Water Drive and Steam Drive Under Different Temperature in Gaosheng Oil Field

Figure 8: The Effect of Drive Type (80°C) on Displacement Efficiency in Jin 45 Heavy Oil Reservoir
Figure 9: The Displacement Efficient Curves (120°C) of the Oil in Well Leng 81 after Adding Chemicals (Petroleum Sulphonate)