Overview of Flow Improvers for Crude Oil Production in China

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Abstract. The production of crude oil has three stages: formation drive, wellbore lifting, and pipeline transportation. This paper summarizes the application effects of flow improvers within several long-distance pipelines in China. The effects of oil- and water-soluble viscosity reducers on lower- and higher-viscosity heavy oils, respectively, and their effects in the wellbore-lifting process are outlined. Further, the technical difficulties and potential solutions associated with driving heavy oil are discussed. This paper has reference value for researchers conducting studies on flow improvers.

Keywords: Heavy oil; Waxy crude; Flow improver; Formation drive; Wellbore lifting; Pipeline transportation.

1. Introduction
Crude oil can be classified according to viscosity as conventional oil, heavy oil, extra heavy oil, or bitumen[1]. Conventional crude oil extracted in China typically has a high wax content[2], high pour point, high viscosity, and poor flow. Because of their high resin and asphaltene contents, heavy oil, extra heavy oil, and bitumen generally have relatively higher viscosities and poorer flows. Heating is commonly used to improve the flow of heavy oil while ensuring safe production. However, flow improvers have the potential to greatly improve the flow of crude oil and could be far more energy efficient and economic.

In recent years, significant progress has been made in the research of flow improvers[3-6]. Based on this research, a series of flow improvers have been developed and proved suitable for the pipeline transportation and wellbore lifting of crude oil.

The flow of conventional crude oil in reservoir conditions is generally sufficient and poses few problems to recovery via water flooding. The flows of heavy oil, extra heavy oil, and bitumen are comparatively poorer, and therefore thermal technology is utilized to drive the flows of these oils. Although water flooding is used to drive normal heavy oil, the associated recovery is only 5%-25% due to the higher viscosity. Although great progress has been made in the research of improving the recovery of heavy oil by water flooding, the work is still in the initial stage, some small-scale field tests have not achieved the expected results, and the main EOR technologies for heavy oil by water flooding has not been developed. Therefore, research into reducing the viscosity of normal heavy oil is vital to improve its recovery via water flooding.
2. Application of Flow Improvers in Crude Oil Pipelines
A combination of heating and flow improvers is commonly used to enhance the flow of conventional crude oil through pipelines, whereas heating alone is commonly used for heavy oil, extra heavy oil, and bitumen.

2.1. Composition of Crude Oil Transported via Various Pipelines in China
Onshore pipelines comprise over 80% of the total transportation for crude oil in China, with a total length of over 23,400 km[7]. However, the high wax, resin, and asphaltene contents of crude oil create significant challenges for its transportation via various major pipelines (Table 1).

| Pipeline name      | Pipeline length /km | Design throughput /10^4 ton.y^-1 | Wax % | Resin-asphaltene % |
|--------------------|---------------------|----------------------------------|-------|--------------------|
| Luning pipeline    | 652.6               | 2000                             | 21.1  | 22.7               |
| Zhongluo pipeline  | 290.1               | 500                              | 24.8  | 6.9                |
| Pulin pipeline     | 241.9               | 350                              | 21.8  | 8.2                |
| Weijing pipeline   | 226.4               | 350                              | 30.6  | 10.0               |
| Donghuang pipeline | 251.1               | 1000                             | 18.3  | 21.6               |
| Donglin pipeline   | 171.3               | 1000                             | 19.3  | 20.7               |
| Malhuing pipeline  | 270.0               | 470                              | 17.6  | 20.1               |
| Huage pipeline     | 438.8               | 300                              | 20.6  | 10.7               |
| Kuchen pipeline    | 476.0               | 1000                             | 8.8   | 6.5                |
| Dongxin pipeline   | 93.0                | 540                              | 18.9  | 20.6               |
| Hongjing pipeline  | 210.1               | 350                              | 15.8  | 13.3               |

2.2. Application Results of Flow Improvers in Crude Oil Pipelines
Based on studies of the mechanisms underlying pour-point depression[8-12], flow improvers have been developed and utilized to successfully adapt crude oil for transportation via various pipelines, including Luning, Zhongluo, and Pulin (Table 2).

Pour point[13] was determined according to Chinese Petroleum and Natural Gas Industry standard SY/T0541-2009. Viscosity[14] was determined according to Chinese Petroleum and Natural Gas Industry standard SY/T0520-2008.

Table 2. Effects of flow improvers on crude oil transported via various pipelines in China.

| Source of crude oil | Dosage /mg.kg^-1 | Pour point °C | Viscosity /mPa.s | Viscosity reduction % |
|---------------------|-------------------|---------------|-------------------|-----------------------|
| Luning pipeline     | 50                | 25            | 7                 | 963(30°C) 320(30°C) | 67                     |
| Zhongluo pipeline   | 40                | 33            | 12                | 1122(30°C) 75(30°C) | 93                     |
| Pulin pipeline      | 40                | 33            | 13                | 763(30°C) 35(30°C)  | 95                     |
| Weijing pipeline    | 60                | 36            | 24                | 1650(30°C) 102(30°C) | 94                     |
| Donghuang pipeline  | 40                | 17            | 5                 | 416(30°C) 306(30°C) | 26                     |
| Donglin pipeline    | 50                | 23            | 5                 | 528(30°C) 307(30°C) | 42                     |
| Malhuing pipeline   | 120               | 18            | -1                | 1686(10°C) 78(10°C) | 96                     |
| Huage pipeline      | 110               | 33            | 16                | 2175(20°C) 226(20°C) | 90                     |
| Kuchen pipeline     | 20                | 1             | -8                | 313(5°C) 22(5°C)  | 93                     |
| Dongxin pipeline    | 15                | 28            | 10                | 2218(20°C) 457(20°C) | 79                     |
| Hongjing pipeline   | 50                | 35            | 21                | 236(35°C) 56(35°C)  | 76                     |

Table 2 shows that the addition of flow improvers produced superior pour-point depressions and reductions in viscosity, with treatments of 15-20 mg/kg reducing pour points by 9-1 °C and viscosities by 26%-6%. The application of flow improvers in these pipelines has resulted in substantial reductions in fuel and transportation costs in addition to significant economic and social benefits. Further, the operational safety and adaptability of pipeline transportation has been improved.
3. Application of Viscosity Reducers in Wellbore Lifting of Heavy Oil

Oil- and water-based viscosity reducers have been developed specifically for the characteristics of heavy oil extracted in China and based on studies of viscosity-reduction mechanisms[15]. Subsequently, these viscosity reducers have been utilized in the wellbore lifting of heavy oil[16].

3.1. Application of Oil-based Viscosity Reducers in Wellbore Lifting

Oil-based viscosity reducers are composed of macromolecule polymers containing strong polar groups that form hydrogen bonds with resin and asphaltene molecules and thereby reduce the viscosity of heavy oil. Therefore, oil-based viscosity reducers are suitable for the production of heavy oils with lower water contents and viscosities.

The data presented in Table 3 show that the viscosities of various lower-viscosity heavy oils were significantly reduced by the addition of oil-based viscosity reducers.

| Source of crude oil       | Dosage /mg.kg⁻¹ | Viscosity (40°C) /mPa.s | Viscosity reduction /% |
|---------------------------|-----------------|-------------------------|------------------------|
|                           | Before treatment| After treatment         |                        |
| Jidong oilfield           |                 |                         |                        |
| 111-6                     | 500             | 4600                    | 810                    | 82          |
| 111-9                     | 500             | 1600                    | 358                    | 77          |
| 109-6                     | 500             | 910                     | 360                    | 60          |
| Huabei oilfield           |                 |                         |                        |
| 200                       | 1513            | 376                     | 75                     |
| Jilin oilfield            |                 |                         |                        |
| 450                       | 2520            | 360                     | 86                     |
| Kelamayi oilfield         |                 |                         |                        |
| 450                       | 2300            | 510                     | 78                     |

Dosages of 200–500 mg/kg produced viscosity reductions of 60%–86% in the lower-viscosity heavy oils that were tested.

In Jidong oilfield, the early stages of oil production conformed to expectations, and considerable production improvements were achieved with the utilization of oil-based viscosity reducers, as the results in Table 4 indicate.

3.2. Application of Water-based Viscosity Reducers in Wellbore Lifting

Water-based viscosity reducers are composed of surfactants and stabilizers that convert an oil–water system into an O/W emulsion and can therefore reduce the viscosity of a heavy oil by over 90%.

In the wellbore-lifting process, a viscosity reducer can be used either alone via injection into the bottom-hole or in combination with steam stimulation. The data presented in Table 5 illustrate the application effects of water-based viscosity reducers on various heavy oils.
Table 5. Effects of water-based viscosity reducers on various heavy oils.

| Source of crude oil       | Dosage /mg.kg\(^{-1}\) | Oil:water/w:w | Viscosity /mPa.s | Viscosity reduction /% |
|---------------------------|-------------------------|----------------|------------------|-----------------------|
|                           | Before treatment             | After treatment |                  |                        |
| Shengli oilfield          | 150                      | 6:4            | 48600 (60°C)     | 147 (60°C)            | 99                     |
| Jidong oilfield           | 150                      | 6:4            | 22750 (40°C)     | 156 (40°C)            | 99                     |
| Xinjiang oilfield         | 200                      | 6:4            | 11090 (30°C)     | 136 (30°C)            | 98                     |
| Liaohe oilfield           | 150                      | 6:4            | 68500 (50°C)     | 159 (50°C)            | 99                     |

Further, a water-based viscosity reducer was utilized in several oil wells in the Xinglongtai oil production plant in Liaohe, and the results are presented in Table 6.

Table 6. Application results of a water-based viscosity reducer for the Xinglongtai of the Liaohe oilfield.

| Well number | Steam cycle /round | Water recovery /% | Increment of water recovery /% | Oil production /ton | Increment of oil production /ton | Production time /d | Increment of production time /d |
|-------------|--------------------|-------------------|-------------------------------|---------------------|-----------------------------------|--------------------|-------------------------------|
| 3547        | 3                  | 47.7              | 7.5                           | 2685                | 1280                              | 165.2              | 47.3                          |
|             | 4                  | 55.2              |                               | 3965                |                                   | 212.5              |                               |
|             | 2                  | 58.5              | 392                           | 3965                |                                   | 279                | 191.5                         |
| 37431       | 3                  | 96.0              | 37.5                          | 2356                | 279                               | 171.7              | 19.8                          |
|             | 3                  | 41.2              |                               | 1716                |                                   | 209.1              |                               |
| 37436       | 4                  | 68.6              | 27.4                          | 1900                | 184                               | 218.7              | 9.6                           |
|             | 5                  | 85.3              | 58.2                          | 1927                | 1173                              | 131.7              | 64.9                          |
| 3126        | 4                  | 27.1              |                               | 3100                |                                   | 196.6              |                               |
|             | 5                  | 85.3              | 58.2                          | 3100                |                                   | 196.6              |                               |
| Wa 38       | 4                  | 35.7              | 20.5                          | 568                 | 798                               | 58.5               | 77.4                          |
|             | 5                  | 56.2              |                               | 1366                |                                   | 135.9              |                               |

Water recovery, production time and oil production of the Xinglongtai increased significantly. According to statistical data provided by the oil production plant, the cumulative increment reached 30,690 tons and the return on investment was as high as 23:1.

4. Viscosity Reducer for Heavy Oil Formation Drive

For conventional crude oils with low in-situ viscosities, water flooding is the primary recovery method. For heavy oils with higher viscosities, thermal recovery methods are utilized, including steam stimulation, steam flooding, in-situ combustion, and steam-assisted gravity drainage. For heavy oils with lower viscosities, water flooding is used.

Heavy oils that can be recovered by water flooding account for 30.1% of the total reserves and 18% of the total production. However, due to the thickness of heavy oil and the heterogeneity of typical heavy oil reservoirs, water flooding yields only 5%–25% of the final oil recovery.

To improve the oil recovery factors of water flooding in heavy oil reservoirs, most research has focused on alkaline, polymer, surfactant, and combination flooding. Promising theoretical research conducted in this area includes proposals for technologies that have been subsequently field-tested\cite{17-21}. For example, a small-scale field test of a viscosity reducer was implemented in the No. 3 oil production plant in the Dagang oilfield in China. However, the small molecules that comprise the viscosity reducer were unable to form stable O/W emulsions under a low in-situ shear rate, and therefore incremental oil production was negligible.

Studies show that the key to improving water drive recovery factors in heavy oil reservoirs is to increase the swept volume. Although reducing the viscosity of heavy oil and increasing the viscosity of the displacement phase are effective ways to increase the swept volume, no research has been conducted on water-flooding enhanced oil recovery (EOR) technologies that could achieve this under low shear stress conditions. A macromolecular viscosity reducer created according to a theoretical molecular design could assist in reducing heavy oil viscosity while increasing displacement phase...
viscosity, and such synergism could greatly improve the recovery factors of water flooding in heavy oil reservoirs. Therefore, with their promising range of applications, macromolecular viscosity reducers are among the key technologies to augment water flooding in the near future, and are of great significance to the development of water-flooding EOR technologies for heavy oil.

5. Conclusions and Proposals
Flow improvers are effective in reducing the pour points and viscosities of waxy crude oils, and have been utilized in the Luning, Zhongluo, and Pulin pipelines (among others) to improve operational safety and adaptability.

Oil-based viscosity reducers are effective on lower-viscosity heavy oils, whereas water-based viscosity reducers are effective on higher-viscosity heavy oils. Both oil- and water-based viscosity reducers have been utilized effectively in wellbore lifting.

However, to enhance formation drive, further research needs to be conducted on viscosity reducers, including viscosity-reducing mechanisms, evaluation systems, and the design of molecular structures.

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