Research and development of viscosity reducer for oil well production fluid in cold transportation

Zhi Ma1*, Changfeng Wang2, Zhonghai Qin1, Xiaolong Gao3, Lili Wei1, Na Su1, Danqing Huang3, Juan Xie1, Zhiguo Zhu4, Donghuan Zhou5

1 Engineering Technology Research Institute of Huabei Oilfield Company, Renqiu, Hebei, 062552, PR of China
2 Huabei Petroleum Tiancheng Industrial Group Co.Ltd Hebei, Renqiu, Hebei, 062552, PR of China
3 Exploration and Development Research Institute of HuaBei Oilfield Company, Renqiu, Hebei, 062552, PR of China
4 The Third Exploit Factory of HuaBei OilField Company, Hejian, Hebei,062450, PR of China
5 The Fifth Exploit Factory of HuaBei OilField Company, Xinji, Hebei,052360, PR of China

Abstract. In view of the situation that heavy oil well production fluid needs to be gathered and transferred by heating or with heat water to ensure the normal operation, a kind of cold transportation viscosity reducer was developed through the compounding of different types of surfactants and the screening of functional additives, which adapt to the oil well produced fluid without heating or watering gathering process, for saving energy, reducing consumption and increasing efficiency, while meeting the environmental needs. After on-site practical applications of 30 pipelines with different physical properties of crude oil, the average pressure of gathering pipelines dropped 1.3 Mpa, which has achieved good results. Application results show that the cold transportation viscosity reducer has strong adaptability and less usage, and it has no influence on demulsification, while having a high value of applications and a broad market prospect.

1. Introduction
In general, the produced fluid in the process of oilfield production will be pumped through oil pipes to oil gathering, transportation and metering station and then a combination station for further processing. The produced fluid in the heavy oil reservoirs and wells is generally gathered and transported via heating (heat tracing) or mixing hot water. The selected and applied crude oil gathering and transportation technical process will directly influence the daily production and operation management of the whole oilfield, even the exploitation and construction, exploitation benefits and ecological environment.

Till now, the most remarkable approach is to add chemical agents to lower wax precipitation temperature and improve the low-temperature fluidity of crude oil, because the molecule of chemical agents can co-crystallize, absorb and interact with petroleum wax, and such interaction will alter the
wax crystal morphology (size and shape) in the crude oil. In this way, wax-crystal structure will be more compact, and small wax-crystal structures are driven to form larger aggregations, which substantially reduces the wax-oil inter-facial area, and compromises the formation of three-dimensional wax-crystal network. As a result, at the macro level, the wax precipitation temperature can be lowered and the low-temperature fluidity of crude oil can be improved, thus achieving the goal of low-temperature transportation of the produced fluid from heavy oil reservoirs and wells through oil pipes, which can serve as technical guarantee for saving energy, reducing consumption, decreasing costs and increasing benefits.

Low-temperature transportation[1] of the produced fluid from heavy oil reservoirs via adding chemical agents is featured with simple operation, less equipment investment, free from post-processing, easy to achieve automatic management on oil transportation process and other advantages; meanwhile, it is also one of effective ways to pump high wax content oil under normal temperature and improve restart of crude oil upon shutdown, which means that this technology has promising application prospects and promotion value.

2. Physical Property Analysis and Fluidity Evaluation on Produced Fluid

2.1. Physical property analysis on crude oil
DSY-006A Solidifying Point Tester is adopted to measure the solidifying point of crude oil; HAAKE MARS Rheometer is adopted to measure apparent viscosity, viscosity-temperature curve, yield stress and wax precipitation temperature. This paper, according to the relevant industry standards, analyzed physical properties of crude oil from the produced fluid of different reservoirs, with the analysis results in Table 1.

| Reservoir | Viscosity (mP•S) at 50℃ | Density (g/cm³) at 20℃ | Freezing point (℃) | Wax content (%) | Asphaltene content (%) |
|-----------|-------------------------|------------------------|--------------------|-----------------|------------------------|
| A321      | 8.73                    | 0.8957                 | 31                 | 14.25           | 16.3                   |
| A69-35    | 10.14                   | 0.8674                 | 27                 | 14.6            | 16.7                   |
| H114-2    | 4.45                    | 0.8526                 | 22                 | 28.05           | 7.68                   |
| H114      | 4.88                    | 0.8748                 | 22                 | 22.26           | 19.46                  |
| H115-3    | 4.40                    | 0.8622                 | 23                 | 30.00           | 10.89                  |
| H107      | 7.50                    | 0.8643                 | 26                 | 29.89           | 15.08                  |

According to the analysis results, the crude oil contains high content of wax, colloid and asphaltene, and these substances are featured with relatively high viscosity to crude oil, and can impede crude oil flow, which are main components forming oil-water inter-facial film; furthermore, molecules of wax, colloid and asphaltene interact and associate with each other to generate hydrogen bond, which can further increase the viscosity of crude oil, given the principle that the more of content of these substances, the stronger the viscosity is.

2.2. Analysis on viscosity of crude oil under different temperatures
Crude oil samples with proper volume from different reservoirs and wells are taken and put into MARS Rheometer to measure the change of viscosity of crude oil under different temperatures at the heating rate of 1℃/min, and corresponding viscosity-temperature curve has been drawn. Please refer to Figure 1, Figure 2, Figure 3 and Figure 4 for test results.

According to the above viscosity-temperature curves of crude oil, the abnormal temperature point of crude oil samples is 30℃. When the temperature is beyond 30℃, the viscosity of crude oil starts to present properties of Newtonian liquid, namely, the viscosity becomes less and less strong along with the increase of temperature; when the temperature is lower than 30℃, the viscosity of crude oil, free from properties of Newtonian liquid, is significantly affected by the decrease of temperature.
3. Development of Viscosity Reducer for low-temperature transportation

3.1. Screening and development of viscosity reducer for low-temperature transportation

3.1.1. Screening different types of surface-active agents [2-4]
This paper, started with changing wax-crystal morphology and growth laws of crude oil, screens the surface active agent that can suppress the growth of wax crystal, lower the viscosity of crude oil and improve the low-temperature flowing property. In this test, crude oil from A321 Well is selected to test and screen different types of surface active agents at 35°C, with results in Figure 5.

The above results show that all different type of surface active agents have certain viscosity reducing effects on crude oil from A321 Well. When the dose of surface active agents is 500mg/L, the
viscosity reduction rate of non-ionic surface active agent XH-33 and XH-31 is 79.73% and 77.57% respectively, while the viscosity reduction rate of anionic surface active agent XH-11 and XH-12 being 75.64% and 76.55% respectively.

3.1.2. Test of compounding surface active agents
In order to improve the viscosity reducing effect\(^{[5]}\) of viscosity reducers for low-temperature transportation and exert the synergistic action between surface active agents, this test is carried out according to the principle of compounding surface active agents. Non-ionic surface active agent XH-33 and anionic surface active agent XH-11 that with excellent viscosity reducing effects are selected for compounding, with test results in Table 2.

Table 2. Influence of Compounding Different Types of Surface Active Agents on Viscosity Reducing Effects.

| XH-33 :XH-11/mass ratio | XH-33 osage/g | XH-11 dosage/g | reduction rate/% |
|-------------------------|--------------|----------------|-----------------|
| 1 : 1                   | 500          | 500            | 75.1            |
| 1 : 2                   | 330          | 670            | 83.4            |
| 1 : 3                   | 250          | 750            | 85.5            |
| 2 : 1                   | 670          | 330            | 89.3            |
| 3 : 1                   | 750          | 250            | 86.6            |

Compounding test results show that, at the same dose of 500mg/L, the viscosity reducing effect of compounded different types of surface active agents is proven to be better than that of single surface active agent to different extent. When the compounding ratio between non-ionic surface active agent XH-33 and anionic surface active agent XH-11 is 2:1 (mass ratio), their viscosity reduction rate is 89.3%.

3.1.3. Test of screening functional additives
When transporting the produced fluid from wells at low temperature, in addition to reducing the viscosity of gathered and transported crude oil at low temperature, approaches shall also be taken to suppress the growth, gathering of wax crystal in the gathered and transported crude oil of produced fluid, lower the inter-facial tension of oil-water mixture, and then improve its flowing property. Therefore, functional additives that can suppress changes of crystal morphology of wax in the crude oil and significantly lower inter-facial tension are introduced into the low-temperature transportation viscosity reducer system.

In this paper, different types of functional additives at different doses are added into the compounded non-ionic surface active agent XH-33 and anionic surface active agent XH-11 at the compounding ration of 2:1 for experiment, with test results in Table 3.

Table 3. Influence of Functional Additives on Viscosity Reduction Rate.

| HS-2, mg/L | reduction rate/% | QH-1, mg/L | reduction rate/% |
|------------|------------------|------------|-----------------|
| 0          | 89.2             | 0          | 88.9            |
| 100        | 91.4             | 100        | 90.3            |
| 200        | 95.8             | 200        | 92.6            |
| 300        | 96.1             | 300        | 93.8            |

The test results show that these two introduced functional additives can effectively improve the viscosity reduction rate of crude oil, and along with the increase of dose, its viscosity reduction rate also gets better. Wherein, when HS-2 functional additive is added, the viscosity reduction rate is strikingly improved, and when at the dose of 200mg/L, the viscosity reduction rate can be up to 95.8%.
3.2. Evaluation on the performance of low-temperature transportation viscosity reducer

3.2.1. Influence of low-temperature transportation viscosity reducer at different doses on crude oil’s solidifying point

Take crude oil from different wells with proper volume to test the influence of low-temperature transportation viscosity reducer at different doses on crude oil’s solidifying point, with test results in Table 4.

Table 4. Influence of Low-Temperature Transportation Viscosity Reducer at Different Doses on Crude Oil’s Solidifying Point.

| Dosage mg/L | freezing point / °C |
|-------------|----------------------|
|             | Well H115-3 | well H114 | well A321 | well A69-35 |
| 0           | 23         | 22       | 31       | 27         |
| 50          | 21         | 20       | 29       | 26         |
| 100         | 18         | 19       | 28       | 25         |
| 200         | 15         | 18       | 26       | 24         |
| 300         | 10         | 12       | 24       | 22         |
| 400         | 10         | 12       | 24       | 22         |

Table 4 shows that the crude oil’s solidifying point decreases along with the increasing dose of low-temperature transportation viscosity reducer. When 300 mg/L dose of low-temperature transportation viscosity reducer is applied, its solidifying deduction rate gets larger, and the solidifying reduction effect does not change along with further increase of dose. Therefore, the recommended dose is 300mg/L.

3.2.2. Influence of low-temperature transportation viscosity reducer at different temperatures on crude oil’s viscosity

Add 300mg/L low-temperature transportation viscosity reducer to produced fluid samples of some wells, and then test the viscosity changes at different temperatures, with test results in Table 5-1 and Table 5-2.

Table 5-1. Viscosity of A115-3 Well’s Crude Oil before and after Adding Viscosity Reducer.

| temperature/℃ | Viscosity before dosing /mP•S | Viscosity after dosing /mP•S |
|---------------|-------------------------------|-------------------------------|
| 10            | 650                           | 80                           |
| 15            | 1250                          | 665.6                        |
| 20            | 918.2                         | 175.2                        |
| 25            | 188.8                         | 26.31                        |
| 30            | 8.5                           | 8.1                          |
| 35            | 5.82                          | 5.04                         |
| 40            | 4.96                          | 4.41                         |
| 45            | 4.45                          | 3.96                         |
| 50            | 3.91                          | 3.46                         |

Table 5-2. Viscosity of A115-3 Well’s Crude Oil before and after Adding Viscosity Reducer.

| temperature/℃ | Viscosity before dosing /mP•S | Viscosity after dosing /mP•S |
|---------------|-------------------------------|-------------------------------|
| 10            | 9125.4                        | 6387.2                        |
| 15            | 5237.7                        | 3142.3                        |
| 20            | 2193.5                        | 1096.5                        |
| 25            | 820.4                         | 377.4                         |
| 30            | 319.7                         | 191.4                         |
| 35            | 131.9                         | 20.3                          |
| 40            | 26.6                          | 18.6                          |
| 45            | 16.1                          | 13.3                          |
| 50            | 10.1                          | 9.7                           |

According to the above results, adding low-temperature transportation viscosity reducer can effectively improve crude oil’s low-temperature fluidity and reduce the viscosity. The viscosity reduction rate of H115-3 Well’s crude oil at 20°C is 86%, and 85% for A69-35 Well’s crude oil at 35°C.

3.2.3. Influence of low-temperature transportation viscosity reducer on crude oil’s yield value

Crude oil’s yield value refers to the minimum shearing stress required when the crude oil with wax-crystal network structure starts to flow at certain temperature. The yield value can directly reflect the strength of network structure of wax in the crude oil at the crude oil’s solidifying point. The large the yield value is, the lower the degree of dispersion of anti-wax viscosity-reduction technology onto
crude oil’s wax crystal is; otherwise, the degree of dispersion will get higher. When the yield value is small, its low-temperature liquidity is excellent, which is an important indicator to measure the performance of wax-content crude oil pipeline restart upon shutdown. The influence of low-temperature transportation viscosity reducer on crude oil’s yield value is in Table 6.

Table 6-1. Influence of Low-Temperature Transportation Viscosity Reducer on Crude Oil’s Yield Value (measured at 35℃).

| Well name | Yield value blank value, Pa | 300mg/L Viscosity reducer, Pa | Yield reduction rate, % |
|-----------|---------------------------|-------------------------------|-------------------------|
| A321      | 324                       | 81                            | 75                      |
| A69-35    | 562                       | 123                           | 78                      |

Table 6-2. Influence of Low-Temperature Transportation Viscosity Reducer on Crude Oil’s Yield Value (measured at 20℃).

| Well name | Yield value blank value, Pa | 300mg/L Viscosity reducer, Pa | Yield reduction rate, % |
|-----------|---------------------------|-------------------------------|-------------------------|
| H107      | 81.6                      | 6.52                          | 92                      |
| H14       | 26.55                     | 1.75                          | 95                      |
| H114-2    | 20.11                     | 1.41                          | 93                      |
| H115-3    | 35.17                     | 1.05                          | 97                      |

According to the above results, the measured yield value of crude oil’s samples from different wells after adding low-temperature transportation viscosity reducer declines remarkably. The reduction rate of crude oil’s yield value at 35℃ is more than 75%, and more than 92% at 20℃.

4. Field Application and Effects

Oil extraction plants affiliated to Huabei Oilfield have applied 30 gathering and transportation pipeline since June 2017, and all of them have delivered excellent performance. Wherein, in 2018, low-temperature transportation viscosity reducer was promoted and applied in 6 zones of No.3 Oil Extraction Plant, with the total utilization amount of low-temperature transportation viscosity reducer up to 110t, and average reduction of pressure of gathering and transportation pipeline by 1.3MPa.

For example, in Lu70-10X Well gathering and transportation system, this circular flow involves 6 wells, and 3 wells of them are oil extraction wells, with the daily fluid volume being 80m³ and daily oil extraction volume being 1.3t. Since November 16, 2018, low-temperature transportation viscosity reducer starts to be added into Lu70-10 point of adding chemicals, and under the conditions that no hot water is mixed, the pressure of single-wellhead’s gathering and transportation pipeline after constant dose at the rate of 300mg/l, is 0.5MPa, and the pressure at the terminal entry gathering and transportation pipeline reduces to 0.22MPa, meeting the expectation.
5. Conclusion

(1) The low-temperature transportation viscosity reducer system developed for practical production process canceling heating (heat tracing) or mixing hot water into well’s produced fluid gathering and transportation pipeline, is featured with powerful adaptability and striking application effects, and can be adjusted according to crude oil’s physical properties and actual production conditions of different wells, thus achieving large-scale application.

(2) This low-temperature transportation technology, by adopting the way of constantly adding low-temperature transportation viscosity reducer at the well inlet and outlet, and canceling the premise of heating (heat tracing) or mixing hot water, can effectively change the flowing property of the produced liquid, and the gathering and transportation pipeline applied into wells and circular flow has achieved the low-temperature gathering and transportation of the produced fluid, thus being widely recognized and popular by oil extraction plants.

References
[1] Yongbo Ji, Jianxing Zhao, (1992) crude oil unheated transportation technology of Huabei Oilfield [J], oil and gas field surface engineering, 11 (5): 1-4.
[2] Quan Wang, (1993) selection of Chemical additives on crude oil production and transportation [J], drilling and production technology, 1993, 16 (4): 48-55.
[3] Jian Fang, Xuantao Liu, Tao Jiang et. (2010) [J], application of viscosity reducer BHJN-14 on heavy oil pipeline transportation [J], progress in fine petrochemical industry, 11 (5): 33-36.
[4] Qinxiang Zheng, (2006) emulsion viscosity reduction and transportation method heavy oil [J], oil and gas field surface engineering, 25 (4): 6-7.
[5] Qiang Sun, Longshe Shen, (2009) viscosity reduction test of ultra heavy oil with water soluble emulsion viscosity reducer [J], 28 (2): 43-47.