Application and Challenge of Flow Improver for the Development of Heavy Oil and Waxy Crude

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Keywords: Heavy oil, Waxy crude, Development , Flow improver, Application

Abstract: This paper outlined the composition of some flow improvers and their applications in long-distance pipeline transportation in China, thereafter compared the effectiveness of using oil-based and water-based viscosity reducers in both low-viscosity and high-viscosity heavy oil wells in China. At the end, this paper summarized challenge in the research of viscosity reducer for the heavy oil formation drive.

1 INTRODUCTION

Generally speaking, the production of crude oil has three stages: formation drive, wellbore lifting and pipeline transportation. According to its viscosity, crude oil can be classified as conventional oil, heavy oil, extra heavy oil and bitumen (Li et al., 1990).

The conventional crude oil in China normally features high wax content (Wang,1995), high pour point and viscosity, and poor flow. Because of high resin and asphaltene content, heavy oil, extra heavy oil and bitumen generally have even higher viscosity and poorer flow. In order to improve the flow of crude oil meanwhile ensure safety in production, heating is commonly used in the production of heavy oil. Flow improvers are generally believed to have the potential to greatly improve the flow of crude oil; furthermore, they could be far more energy-efficient and economic.

After years of arduous work, Scientists worldwide have made great progress in the research of flow improvers (Barasha et al., 2018; Pranab and Moumita, 2014; Hafiz and Khidr, 2007; Zhang et al., 2014; Khidr, 2011; Deshmukh and Bharambe, 2009; Nassar, 2008; Du et al., 2012; Ahmed et al., 2014), a series of which were developed and proved to be suitable for the pipeline transportation and wellbore lift of crude oil. Flow improvers have been widely used in pipelines and wellbores (Bai et al., 2016; Qin et al., 2012; Luo et al., 2015; Liu et al., 2017; Jiang et al., 2013; Ma et al., 2017), and moreover brought forth substantial economic and social benefits.

In reservoir conditions, for conventional crude oil, its flow is generally good, which poses little problem to formation drive, water flooding is used. In comparison, for heavy oil, extra heavy oil and bitumen, because its flow is poor, thermal technology is mainly used to solve the difficulties of formation drive. For normal heavy oil, water flooding is used, but the oil recovery of water flooding is only 5-25%, the main reasons is the higher viscosity of normal heavy oil, so the study of viscosity reducer for normal heavy oil has great significance to improve oil recovery of its water flooding.

2 APPLICATION OF FLOW IMPROVER IN CRUDE OIL PIPELINE

To combat flow loss in pipeline transportation, for conventional crude oil, heating combined with flow improvers are commonly used; while for heavy oil, extra heavy oil and bitumen, heating is commonly used.

2.1 Composition of China's Crude Oil Transported by Some Pipelines

China's onshore oil pipeline has a total length of over 23,400 kilometers (Zhang, 2016). Pipelines are the main means of transportation for crude oil, accounting for over 80%. For some major oil

Zhang, F., Guan, B., Liu, G., Li, X., Zhu, Z. and Su, H.
Application and Challenge of Flow Improver for the Development of Heavy Oil and Waxy Crude.
DOI: 10.5220/0008185900770082
In *The Second International Conference on Materials Chemistry and Environmental Protection (MEEP 2018)*, pages 77-82
ISBN: 978-989-758-360-5

pipelines of China, crude oil has high wax, resin and asphaltene content, which brings about great challenges for pipeline transportation (Table 1).

2.2 Application Results in Crude Oil Pipeline

Based on studies of pour point depressing mechanisms (Zhang and Wang, 1995), flow improvers (Zhang et al., 1999a; Zhang et al., 1999b; Cao and Li, 2004; Li et al., 1989; Wang, 2013; Li, 2010; Dang et al., 1996; Bi, 1992) was developed and has demonstrated good adaptability and modification results for crude oil transported by some pipelines such as Luning, Zhongluo and Pulin et al. in China (Table 2).

Table 2 shows that flow improvers produced good pour point depression and viscosity reduction results. With treatment of 10-100mg/kg, pour point dropped 12℃-23℃, and viscosity dropped 16%-98%. Through its applications in the pipelines, we have seen great savings in fuels and transportation costs, and moreover significant economic and social benefits. On the other hand, operational safety and adaptability of pipeline transportation have been improved.

Table1: Some pipeline parameters and composition of transported crude oil in China.

Pipeline	Pipeline length /km	Design throughput /10^4 ton/y	Wax /%	Resin and asphaltene /%
Luning	652.6	2000	20.60	23.70
Zhongluo	290.1	500	24.59	6.81
Pulin	241.9	350	21.40	8.00
Weijing	226.4	350	30.80	9.90
Donghuang	251.1	1000	18.30	21.60
Donglin	171.3	1000	19.10	20.80
Mahuining	270.0	470	17.90	20.10
Huage	438.8	300	22.60	11.80
Kushan	476.0	1000	8.84	6.47
Dongxin	93.0	540	19.60	21.50
Hongjing	210.1	350	14.80	13.27

Table 2: Effect of flow improvers on some pipeline's crude oils in China

Pipeline	Dosage /mg/kg	Pour point /℃		Pour point reduction /℃	Viscosity(30℃) /mPa.s		Viscosity reduction /%
		Before treatment	After treatment		Before treatment	After treatment	
Luning	40	24	5	19	935	300	68
Zhongluo	50	33	13	20	1172	60	95
Pulin	50	33	15	18	763	19	98
Weijing	50	37	23	14	1720	119	93
Donghuang	50	17	4	13	396	334	16
Donglin	50	23	3	20	408	314	23
Mahuining	100	18	-5	23	1716①	41①	97
Huage	100	33	15	18	2365②	256②	89
Kushan	11	1	-11	12	293③	32③	89
Dongxin	10	27	10	17	2418④	476④	80
Hongjing	50	33	22	11	192⑤	48⑤	75

Note: ①8℃; ②20℃; ③2℃; ④20℃; ⑤35℃

3 APPLICATION OF VISCOSITY REDUCERS IN HEAVY OIL WELLBORE LIFTING

According to the characteristics of heavy oil in China and based on studies of viscosity reduction mechanisms (Zhang and Wang,1995), both oil-based and water-based viscosity reducers were developed and used in the wellbore lifting of heavy oil (Zhang et al.,1999c).

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

Oil-based viscosity reducer is composed of the macromolecule polymers containing the strong polar groups. The groups with strong polarity in its molecules and those in the molecules of resin and asphaltene form hydrogen bonds, which have good viscosity-reducing effect for heavy oil. Therefore, oil-based viscosity reducers are suitable for the production of heavy oil with low water content and low viscosity. Viscosity of some heavy oil with low viscosity was significantly reduced, results are shown in Table 3.

Table 3 shows that dosage of 250-300mg/kg, the viscosity of above-mentioned heavy oil dropped 46%-91%.

In the early production stage of Block 104-5, oil production were well under expectation. Great production improvements were achieved after the treatment of oil-based viscosity reducers, as shown in Table 4.

Table 4 shows that after the treatment of oil-based viscosity reducers in Block 104-5, both oil production time and rates were increased. Production improvements were obvious that daily oil production rate increased from 20 tons to 230 tons.

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

Water-based viscosity reducer is composed of surfactants and emulsion stabilizers. It is able to turn an oil-water system into an O/W emulsion, reducing the viscosity of heavy oil by over 90%.

In the wellbore lifting process, the viscosity reducer can be used alone by injecting into the bottomhole or with steam stimulation. The viscosity reduction effect is shown in Table 5.

Water-based viscosity reducer was used in a number of oil wells in Wa-38 block of Xinglongtai oil production plant at Liaohe. The application results are shown in Table 6.

Table 6 shows that both production days and production rates of Wa38 block increased significantly. According to the statistical data from 15 Wells provided by the oil production plant, accumulative incremental reached 35,870 tons, and return on investment is as high as 26:1.

Table 3: Viscosity-reducing effect of oil-soluble viscosity reducer for some heavy oils.

Oil sample		Dosage /mg/kg	Viscosity (40℃) /mPa.s		Viscosity reduction /%
			Before treatment	After treatment	
104-5 Block, Jidong Oilfield	106-5	300	5500	1100	80.0
	104-5	300	1600	448	72.0
	109-6	300	910	490	46.2
	109-7	300	1230	650	47.2
Namazhuang Huabei oilfield		250	1513	123	91.0
Erlian oilfield		300	2620	360	86.3
Kelamayi		300	2300	460	80.0

Table 4: Application results in Block 104-5 of Jidong Oilfield.

Well number	Production efficiency /%			Time of continuous production /d			Production /ton/d		
	Before treatment	After treatment	Incre-ment	Before treatment	After treatment	Incre-ment	Before treatment	After treatment	Incre-ment
104-6	40	94	54	110	254	144	3.7	4.4	0.7
109-6	43	96	53	81	118	37	5.5	8.3	2.8
111-6	97	98	1	119	129	10	8.4	9.5	1.1
111-7	96	97	1	44	200	156	10.4	10.7	0.3

Table 5: Effect of water-based viscosity reducer for some heavy oils.

Oil sample	Dosage /mg/kg	Oil :Water /w:w	Viscosity /mPa.s		Viscosity reduction /%
			Before treatment	After treatment	
Shengli oilfield	100	6:4	59600 (60℃)	30 (30℃)	>99.95
Jidong oilfield	100	6:4	22750 (40℃)	50 (40℃)	99.80
Kelamayi oilfield	100	6:4	12050 (30℃)	44 (30℃)	99.60
Wa 38 Union, Liaohe oilfield	100	7:3	77600 (50℃)	50 (30℃)	>99.94
	150	7:3	77600 (50℃)	49 (30℃)	>99.94
	200	7:3	77600 (50℃)	55 (30℃)	>99.93

Table 6: Application results in Wa-38 Block of Liaohe oilfield.

Well number	Steam cycle /round	Recovery water /%	Increment of water recovery /%	Oil production /ton	Increment of oil production /ton	Production time /day	Increment of production time /day
3542	2	45.9	8.1	2283	1780	148.3	83.1
	3	54.0		4063		231.4	
37430	1	47.5	77.5	2069	404	168.1	25.6
	2	125.0		2473		193.7	
37435	2	35	29.0	1761	247	243.7	5.0
	3	64		2008		148.7	
3124	5	27.7	58.5	1824	1476	137.5	65.8
	6	86.2		3300		203.3	
36432	2	37.8	35.5	2064	80	179.5	31.7
	3	73.8		2144		211.2	
3743	2	29.9	25.2	470	1143	58.5	137.4
	3	55.1		1613		195.9	

4 VISCOSITY REDUCER FOR HEAVY OIL FORMATION DRIVE

For conventional crude oil with the low in-situ viscosity, water flooding is mainly used as formation drive. For heavy oil with high viscosity, thermal recovery is used, which includes steam stimulation, steam flooding, in-situ combustion and SAGD. For heavy oil with low viscosity, water flooding is used.

In terms of heavy oil, those that can be developed by water flooding accounts for 30.1% of total reserves and 18% of total production. Because of the thickness of oil and the heterogeneity of reservoir, water flooding in normal heavy oil reservoirs could only yield 5-25% final oil recovery.

In an effort to improve oil recovery factor of water flooding in heavy oil reservoirs, most researchers home and abroad previously focused their studies on alkaline flooding, polymer flooding, surfactant flooding and combination flooding etc. Their theoretical research has some merits (Liao and Tang, 2018; Qu, 2013; Tang et al., 2012; Zhou, 2017; Chen, 2013; Jin et al., 2005), besides some technologies proposed were put into field tests. In No.3 oil production plant of Dagang oilfield in China, a small-scale field test using viscosity reducer was implemented. Due to the failure for the small molecule viscosity reducers to form stable O/W emulsions under low in-situ shear rate, incremental oil production was found to be nominal.

Studies show that the key to improving water drive recovery factor in heavy oil reservoirs is to enlarge swept volume. Reducing viscosity of heavy oil and raising viscosity of displacement phase are effective ways to achieve this. Now that there is no research conducted home or abroad on heavy oil water flooding EOR technologies that could reduce heavy oil viscosity meanwhile raising displacement phase viscosity under low in-situ shear stress. This could possibly be achieved by macromolecular viscosity reducers according to the theory of molecular design. The synergism could greatly improve the recovery factor of water flooding in heavy oil reservoirs. Therefore, macromolecular viscosity reducer is one of the key technologies to replace water flooding in the near future. It is of great significance to water flooding EOR of heavy oil and has a promising prospect and range of applications.

5 CONCLUSIONS AND PROPOSALS

Flow improver which has good pour point-depressing and viscosity-reducing effects for the waxy crude oil, had been used in Luning, Zhongluo and Pulin, et al. pipelines and improved safety and adaptability in operations.

Oil-based viscosity reducer which has good viscosity reducing effect for heavy oil with low viscosity, had used to wellbore lifting of low viscosity heavy oil. While water-based viscosity reducer which has good viscosity reducing effect on heavy oil with high viscosity, had used to wellbore lifting of extra heavy oil.

More research needs to be diverted to and focused on viscosity reducers for formation drive, including studies of viscosity reducing mechanisms, evaluation system and molecular structure design.

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