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COMPATIBILITY EVALUATION OF BZ25-1 CRUDE OILS IN BOHAI BAY, CHINA

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ABSTRACT

BZ25-1 oilfield is located in the southeast of Bohai bay which geographically lies between 119^{o}00′ to 119^{o}15′ east longitude and 38^{o}10′ to 38^{o}20′ north latitude. It has two oil blocks, including Shahejie (SHJ) waxy oil and Minghuazhen (MHZ) heavy oil, with six wellhead platforms WHPA~WHPF and six submarine pipelines. Therein, the WHPC-WHPB and WHPB-SPM (Single Point Mooring) pipelines transport the mixture of the two produced crude oils.

However, the mixing of the two oils will certainly bring out a change in their components and properties, which directly affects the safe operation of the submarine pipelines and offshore production facilities. Therefore, this paper compounds three kinds of MHZ/SHJ mixed oils with blending ratios of 1:1, 3:1 and 9:1, mainly studies how the components, rheological and thermophysical properties of the oil mixtures change with the blending ratio. The major objective of this study is to evaluate the compatibility of the two crude oils and provide a theoretical basis for the production optimization and risk elusion of the oilfield.

The results of the study show that the components and properties of SHJ crude oil are quite different from those of MHZ oil, the flow behavior of SHJ oil is more sensitive to temperature. As MHZ oil in the compounds increases, the contents of asphaltene, resin, sulfur and carbon residue will increase except wax contents, their viscosities, densities and flash points will also increase, but their pour points, yield stresses, calorific values and other major thermophysical parameters will decrease. A blending ratio of 2~7:1 for MHZ to SHJ crude oil can be concluded to make the properties of the compounds meet the safe and economic requirements of the subsea pipeline and offshore facility operations and ensure the compatibility of the mixed oils. In actuality, the field operations have confirmed that the recommended blending ratio is reasonable and practicable.

INTRODUCTION

In a general way, wax content of the crude oils declines, and asphaltene increases as the oilfield is exploited. Obviously, the difference of the compositions and properties between SHJ and MHZ crude oil is growing gradually. Therefore, there may be some incompatible problems when they are compounded and transported by a single pipeline, which is summarized as following two aspects.

● **Stratification**: If any two crude oils are incompatible, their compound will stratify while its transportation pipeline has to be shut down due to malfunction or power failure. In that case, the heavy one will deposit at the bottom of the pipeline, and the oil properties will change greatly in different cross-sections of the pipeline, which will cause a potential hazard to restart the pipeline (1).

● **Asphaltene Deposition**: During the production and transportation of the crude oils, there are many factors affecting asphaltene deposition. Their action mechanisms are very complex and some have not been understood and realized thoroughly. At present, the mostly accepted theories on asphaltene deposition are described as the follows (2, 3):

○***Solution Theory*:** It is generally believed that a crude oil with some dissolved asphaltene always presents in a state of true solution. The saturation of the solution depends on the asphaltene solubility. As the asphaltene solubility increases, the amount of asphaltene dissolved in the crude oil also increases. Once the solution with some asphaltenes reaches a saturated state, the asphaltene will deposit from the oil.

○***Colloidal Theory*:** This theory is much more widely accepted, and considers that a crude oil is a colloid system, comprising of some saturate, aromatics, resin and asphaltene. The asphaltene is defined as colloids in the oil phase, and to some extent, stabilized by the resin molecules that act as protective bodies for asphaltene particles. Colloidal asphaltenes can be naturally or artificially precipitated if the resin protective layer is removed from asphaltene-particle surfaces. Asphaltene precipitation and deposition in oil-production systems depend on the changes of production conditions such as pressure, temperature and oil composition. These mainly result in the variation of asphaltene solubility in the crude oil. If the composition is constant, as the pressure and temperature increase, the asphaltene dissolving capacity in crude oil will improve and it is not easy for the asphaltene to deposit.

On the basis of the colloidal theory, some asphaltenes may deposit due to the composition variation of the compound oils while SHJ light oil is added to MHZ heavy oil. If the asphaltenes deposit in the pipeline or production facilities, the crude oil production and transportation will be affected unfavorably, and the production cost will increase significantly, even cause a block or shutdown of the pipelines or facilities.

In order to optimize the production and avoid the potential hazards of the blending transportation for the two crude oils, their compatibility should be evaluated first. Therefore, this paper compounds three kinds of MHZ/SHJ mixed oils with blending ratios of 1:1, 3:1 and 9:1, mainly studies how the compositions, rheological and thermophysical properties of the oil mixtures change with the blending ratio.

A recommanded blending ratio has been provided according to this study. Compared with the actual operations of BZ25-1 oilfield, this conclusion is reasonable and practicable.

EXPERIMENTAL

Oil Samples

- MHZ crude oil, dehydrated and degassed crude oil, sampled from platform E in BZ25-1 oilfield
- SHJ crude oil, dehydrated and degassed crude oil, sampled from the ES3 layer of oil well A5 in BZ25-1 oilfield

Apparatus

XP-300C Image Analytical System: It is composed of micropolariscope, image collection and temperature control units, configured by ourselves as shown in Fig.1, which was used to detect the wax crystallizing and collect the microgram of wax crystals at desired temperatures during cooling a waxy oil sample. It is equipped with a specific image analysis software, which was used to analyze the modality of crystal microstructures.

Fig.1 XP-300C image system

***HAAKE RS600 Rheometer*:** It is a modular high-tech rheometer with integrated CR, CD and CS control loops, which was imported from Thermo Electron Corporation and shown in Fig.2. This rheometer was used to test the rheological properties of oil samples.

Fig.2 HAAKE RS600 rheometer

TURBISCAN MA2000 NIR Scan Analyzer: This analyzer made in American can show the situation of the solution, such as creaming, phase separation, flocculation, coalescence, stability, particle size (ranging from 0.1 to 1000μm), and the rate of sedimentation. Its scanned results aren't affected by the color of solution. It was mainly used to study the uniformity and stability of the crude oils and their compound samples.

METHODS

Preparation of Compound Oils

Three kinds of compound oils were prepared according to the blending ratios of MHZ and SHJ crude oils, i.e. 9:1(simply called M9S1), 3:1(M3S1) and 1:1(M1S1), which are based on their expected production outputs.

Firstly, SHJ and MHZ crude oils were heated to 65℃ respectively and kept for 10~20min to melt any wax crystals completely. Secondly, their 200g blend samples were weighed by using a 0.1mg electrical balance on the above blending ratios respectively. And then they were filled into corresponding mixing jars, which were placed into a 65℃ water bath and kept for 15min. Lastly, the mixing jars were taken out and vibrated for 50~60 times to ensure the uniformity of the compounds. Thus, the compounds were prepared readily.

Test of Compositions and Physical Properties

The compositions, thermophysical and physical properties of two crude oils and their compounds were tested according to the ASTM standards listed in Table 1.

Table 1 Standards of compositions and properties test

Parameter	ASTM Standard
Density（kg/m^3）	D4052-02
Flash point（℃）	D93-00
Gross thermal value（KJ/kg）	D240-92（97）
Net thermal value（KJ/kg）	D240-92（97）
Composition（%）	D3279-97(01)
Viscosity（mPa.s, 50℃）	D445-01
Pour point（℃）	D97-96a
Total sulfur（%）	D4294-98
Total acid number（mg KOH/g）	D664-01

Test of Uniformity

The prepared compound oils with different blending ratios were separately poured into corresponding 500ml graduated cylinders and stood for 6h or 12h at room temperature. Then the viscosities of the compounds sampled at the top and bottom of the cylinders were measured respectively at 50s^{-1} and 20℃ with HAAKE RS600 rheometer.

Test of Stability

The stability of two crude oils and their compounds were tested by TURBISCAN MA2000 NIR Scan Analyzer. First of all, the test model was set to automatic (multiple scan). Then the scanning frequency and interval time of MHZ crude oil, being scanned at room temperature (about 25℃), were set to 24 and 1h separately. In order to study the effect of wax crystallization on the uniformity of SHJ crude oil and its compounds, they were first heated to 65℃and then scanned during their naturally cooling at room temperature, whose scanning frequency and interval time were set to 120 and 1min respectively.

Test of Rheological Properties

The HAAKE RS600 rheometer was used to measure the shear stress-shear rate curves of the oil samples according to "Standard Test Method of Crude Oil Viscosity: Rotation Viscometer Balance Method" (Chinese Petroleum Industrial Standard, CPIS: SY/T 0520-1993). The testing results were processed and fitted with Origin7.0 to plot their viscosity-temperature curves.

Test of Wax Crystallization Properties

The objective of this experiment is to study the effect of MHZ crude oil on the wax crystallization properties of SHJ oil, including Wax Appearance Point (WAP) and Peak Temperature of Wax Precipitation (PTWP). WAP is the temperature at which a few white or bright spots begin to appear on the visual area of the XP-300C system during cooling a waxy oil sample, while PTWP is a temperature range over which the wax crystallizes heavily, which was determined by XP-300C system according to the following procedures.

A little waxy sample was added into a clean glass loading disc with a temperature control system. Then the focus of the system was regulated until a clear visual area appeared. The sample was heated to 65℃ and kept for 10min. Next the loading disc was slightly adjusted to ensure that there were no any incandescent impurities on the visual area, whose location was fixed until the end of this test. Subsequently, the sample was cooled at the rate of 1.0℃/min and interval of 5℃ to a test temperature and kept for 5min, and then the microgram was collected. Thus the WAP and PTWP of a waxy oil sample could be determined.

Test of Yield Stress

Yield stress of a waxy crude oil at low temperatures reflects its structural or non-Newtonian strength. Only the imposed shear stress exceeds its yield stress, can the oil be pushed. It is one of the most important rheological parameters to evaluate the flowability of a waxy oil. Compared with pour point, yield stress of the oil could reflect the trouble extent of restarting its transportation pipeline after shutdown. The yield stress of the two crude oils and their compounds were measured at 1℃ according to "Standard Test Method for Yield Stress of Crude Oil" (CPIS: SY/T 7547-1996).

RESULTS AND DISCUSSION

Compositions and Physical Properties

The compositions and physical properties of the two crude oils and their compounds were listed in Table 2. Thus it can be seen that all of the physical properties such as density, viscosity and acid number, and the contents of asphaltene, resin and sulphur increase as MHZ crude oil in the compounds rises. As a result, the flowability of the compounds becomes worse due to their growing viscosity, and the pressure drop along their transportation pipeline would increase. The increasing acid number would accelerate the corrosion of the oil transportation pipelines and production facilities, and the increasing resin and asphaltene might lead to heavy organic substance deposition and block of the pipelines or facilities, which should be avoided during the oil production and transportation.

However, the wax content and pour point decrease with the ratio of MHZ crude oil in a compound oil increasing due to the high asphaltene and resin content of MHZ crude oil. The surface-active substances such as asphaltene and resin in a crude oil have a certain pour point inhibition and could break down wax crystalline structure and prevent the formation of a net-shaped structure (4). The result of these synergic actions is that the pour points of the compounds will be depressed and a gel-like structure could not be formed easily at low temperatures, which is favourable for them to be transported through offshore pipelines. But the viscosities of the compounds will increase greatly with the increasing MHZ crude oil, thus the energy consumption of their transportation and production will still keep a higher level. As a result, a reasonable blend ratio for the compounds would be determined according to such a principle that both their pour points and viscosities are beneficial for their production and transportation.

Table 2 Compositions and physical properties of the oils

Oil samples / Properties	SHJ	M1S1	M3S1	M9S1	MHZ
Density（kg/m^3, 20℃）	859.5	909.9	933.0	946.8	955.9
Density（kg/m^3, 50℃）	838.1	889.6	913.2	927.2	936.5
Viscosity(mPa.s, 50℃)	8.41	40.14	128.40	316.20	638.40
Freezing point（℃）	26.6	+15.0	+6.0	+1.0	－14.0
Pour point（℃）	28	+17	+8	+3	－11
Wax content（%）	19.90	17.16	13.37	6.08	2.22
Resin content（%）	5.25	12.21	14.50	16.31	16.73
Asphaltene content（%）	4.28	4.92	5.34	5.98	6.85
Sulfur content（%）	0.1200	0.1975	0.2308	0.2531	0.2730
Acid number（mgKOH/g）	0.04	1.05	1.67	1.94	2.10
Open flash point（℃）	23	52	74	106	135
Close flash point（℃）	18	30	38	64	108

Stability

The asphaltene deposition depends on the stability of a crude oil colloid system. There are many methods to evaluate the relative stability of a crude oil, which are carried out based on the test of some physical properties, mainly including viscosity, refractivity, conductivity, electromagnetic emission, laser, heat conduction, granularity, luminous absorption and so on (5). The light scattering and titration methods are widely used in laboratory. The light scattering was used in this paper to evaluate the stability of the compound oils.

The NIR scanning results of two crude oils and their compounds are illustrated in Fig.3. The X-axis denotes the length of glass sample tube, i.e. the vertical scanning distance, while the Y-axis shows the scattering degree. If an oil is unstable, its asphaltene or wax crystals will deposit at the bottom of the sample tube and result in a density difference between the upper oil and the bottom. The stability of the oil can be evaluated by the fluctuation of the back scattering along the vertical sample tube, especially near the bottom. The less the fluctuation of the test curves is, the more stable the oil is.

Their NIR scanning spectrums have no obvious fluctuation during their cooling or standing (see Fig.3), which indicates that the compounds containing 50%~90% MHZ crude oil have a good stability. Because SHJ crude oil belongs to a waxy oil, there will be some waxes in the oil and its compounds to separate and deposit naturally as the temperature drops. But the crystallized wax crystals don't affect their scattering degree evidently, which is probably due to the uniform dispersion of the precipitated wax crystals. Thus it is very clear that there are no incompatible or instable problems while SHJ and MHZ crude oils are compounded by the studied blending ratios.

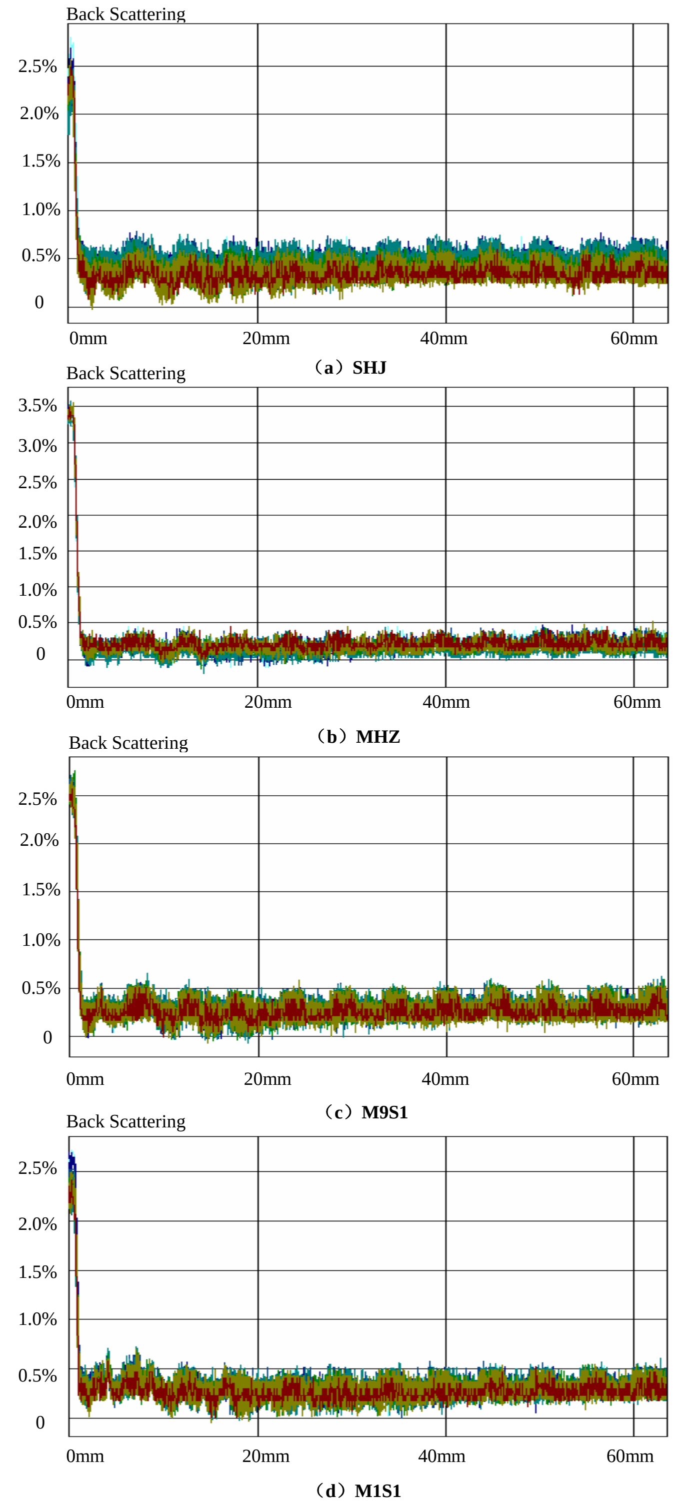


Fig. 3 NIR scanning spectrums of the oils

Uniformity

The viscosities of the stood compounds sampled at the top and bottom of corresponding graduated cylinders were measured at 20℃ and $50s^{-1}$, as listed in Table 3, which shows that there is no notable viscosity difference between the top oil and the bottom after the compounds standing for 6h or 12h at room temperature. Therefore, the two crude oils can be compounded uniformly and don't stratify while standing for a certain time.

Table 3 Viscosities of the stood compounds sampled at different locations of corresponding graduated cylinders

Standing time（h）	Sampled location	Viscosity（mPa.s, 20℃ and $50s^{-1}$）		
		M9S1	M3S1	M1S1
6	Top	3794.6	1765.5	746.89
	Bottom	3775.3	1738.6	760.52
12	Top	3786.6	1729.3	751.54
	Bottom	3748.2	1750.8	732.52

Viscosity vs. Temperature Characteristics

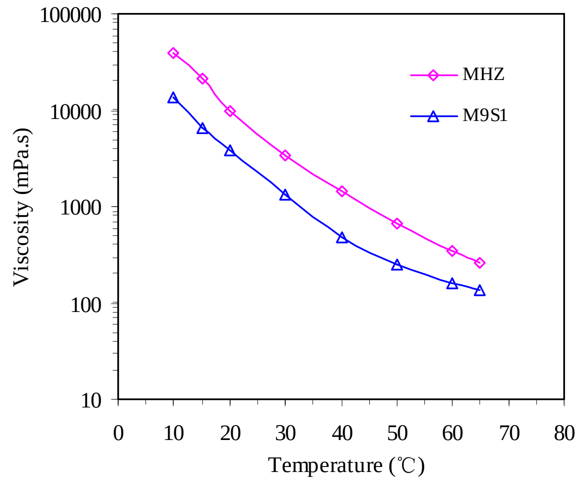
The viscosity of MHZ crude oil has obvious reduction with the mixing of SHJ crude oil, as illustrated in Fig.4. Within the testing temperature, the viscosity vs. temperature curve of the compound M9S1 lies below that of MHZ crude oil, and its viscosity is independent of the shear rate, being similar to MHZ crude oil, and it belongs to a Newtonian fluid. This indicates that the rheological properties of MHZ oil haven't been changed notably by blending SHJ crude oil within the concentration of 10%, but its viscosity at the same temperature has been reduced (Fig.4a).

However, the compound M3S1 exhibits a low viscosity, and is independent of shear rate within a relatively wide temperature range. Once its temperature drops below 20℃, it shows Non-Newtonian properties. The inflexion temperature at which a Newtonian fluid begins to present a non-Newtonian behavior is always called abnormal point of this fluid. So that the abnormal point of the compound M3S1 is about 20℃.

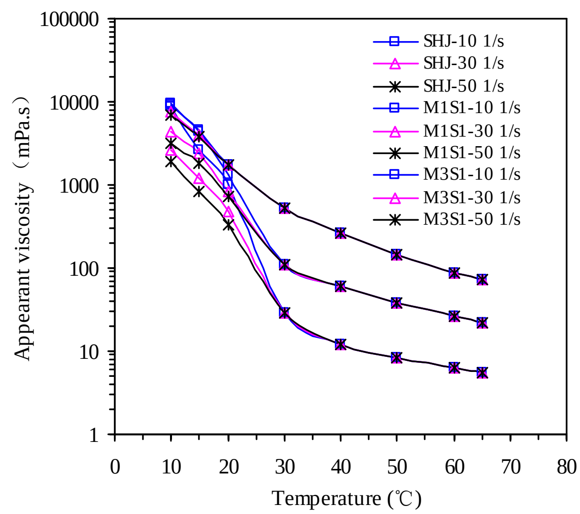
For the compound M1S1 and SHJ crude oils, the deviation of their Newtonian behavior becomes more obvious with temperature dropping, and their apparent viscosities decrease with shear rate increasing, which shows an obvious shear thinning property, and there are some emanative branches with the change of shear rates in their viscosity-temperature curves (Fig.4b). It can be seen that their abnormal points are both about 30℃. Therefore, the compounding of MHZ and SHJ crude oil is useful for depressing the abnormal point of SHJ oil.

Wax Crystallization Properties

In the process of the oil gathering and transportation, the state of heavy organic substances such as wax, asphaltene, resin changes with the temperature and other thermophysical conditions changing (6). The crude oil is generally in a solid (wax)-liquid (oil) phase equation at normal temperature. It can be seen as binary system in which the oil is solvent and wax is solute. All of the waxes dissolve in the oil phase when the oil temperature is high enough, and its solubility in the oil phase decreases as temperature drops. When the wax composition in the oil phase reaches a saturation state, some macromolecular waxes will first begin to crystallize and deposit. If the temperature of inner wall of the pipeline or facilities is lower than the WAP of the transported or processed crude oil, there will be wax deposition on the wall. The flocculation or separation of other impurities or compositions such as asphaltene, resin, sulphur, sand and clay are always followed by the paraffin deposition. As a result, the flow resistance of the crude oil will increase, and the transportation capacity of the pipeline or facility availability will decrease.



(a) Without abnormal point



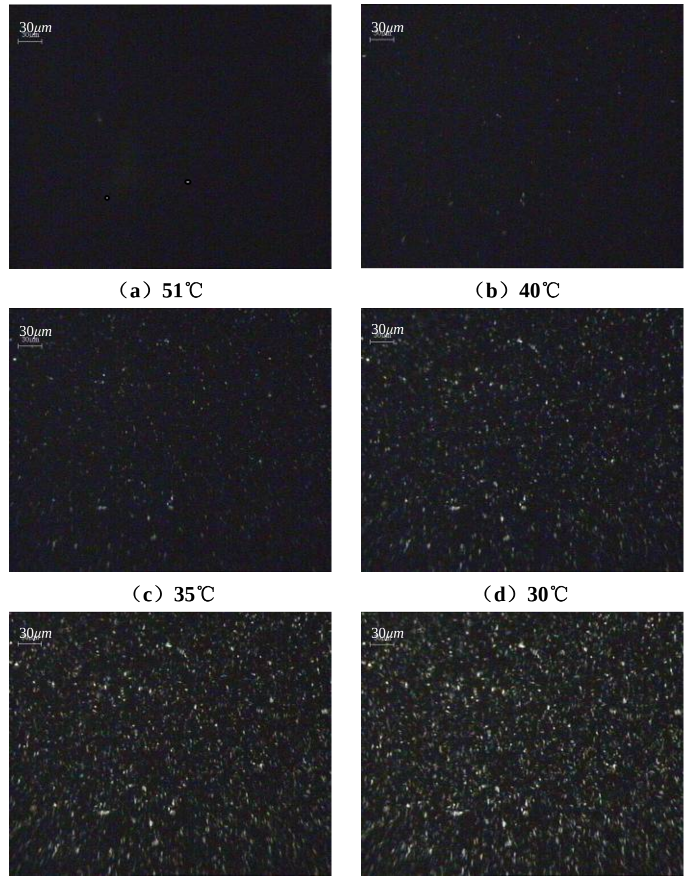
(b) With abnormal point

Fig.4 Viscosity-temperature curves of two crude oils and their compounds

When the wax deposition grows to a certain thickness, the flow area is reduced, and the friction is increased. Even some "bottle necks" could be formed in a few local pipeline segments with higher coefficients of heat transfer such as naked or aerial pipeline segments. So that it is dangerous for them to be pigged. For example, there was a submarine pipeline without pigging for a long time in Bombay offshore field in India. A pig was seized during pigging the pipeline due to lack of enough evaluation on the severity of wax deposition. In order to fetch the pig out, 10 holes had to be drilled on the pipeline, which caused great economic losses (7). Furthermore, during restarting a subsea shutdown pipeline, if the restarting pressure is much higher, part deposits could be eroding away under higher shear action of the oil flow, which makes the flowability of the oil flow worse and leads to an unsafe restarting process. Obviously, the effect of heavy organic deposition on the safe and economic operation of the pipeline is quite unfavorable. Therefore, the wax crystallization properties of the compound oils should be well understood to avoid these potential hazards.

The micrograms of SHJ crude oil during its cooling at some test temperatures are shown in Fig.5. When the oil temperature reaches 65℃, no "bright spot" (paraffin crystalline particle) is observed by XP-300C image system, which shows that the wax crystals have dissolved completely in the oil phase. When its temperature falls to 51℃, a little scattered bright spots can be viewed (Fig.5a), which indicates that a few paraffin molecules have crystallized. When its temperature drops to 40℃ and 35℃ (Fig.5b and Fig.5c), the number of crystalline particles is still small. When its temperature is below 35℃, the amount of wax crystalline particles increases obviously (Fig.5d~5f), and they disperse over the whole liquid phase (visual area) gradually. It is possible for them to interact with each other, form a net-like structure and fill with the whole space of the container eventually. Therefore, the WAP of SHJ crude oil is 51℃, and its PTWP is between 35℃ and 20℃. Thus it is clear that the temperature need to keep above the PTWP for the SHJ crude oil to be transported by offshore pipelines, and the well head temperature should be maintained above 45℃ to prevent paraffin crystalline forming largely and depositing heavily.

The WAPs and PTWPs of the compounds were determined by the same analytical method as listed in Table 4, which shows that the WAPs and PTWPs of the compounds are lower than those of SHJ crude oil. That is to say, MHZ crude oil is capable of reducing the WAP and PTWP of SHJ crude oil. Aditya has also found that the WAP of high waxy oil can be decreased by blending some heavy oil (8). The results of this paper indicate that it can not cause notable reduction in WAP unless the mixed MHZ crude oil exceeds to a certain degree. For example, the WAP of M1S1 with MHZ/SHJ compound ratio of 1:1 is 48℃, and its PTWP is between 30℃ and 15℃, which is close to those of SHJ crude oil. However, for compound oil M9S1, its WAP and PTWP are 42℃ and 15~20℃ separately. Therefore, the blending ratio of MHZ to SHJ crude oil should be controlled to an appropriate range to optimize the WAP, pour point and viscosity of a compound oil.



(a) 51℃ (b) 40℃ (c) 35℃ (d) 30℃ (e) 25℃ (f) 20℃

Fig.5 Micrograms of SHJ oil during cooling

Table 4 Wax crystallization characteristics of SHJ oil and its compounds with MHZ oil

Oil sample	WAP（℃）	PTWP（℃）
SHJ	51	35～20
M1S1	48	30～15
M3S1	47	20～10
M9S1	42	15～10

Yield Stress

The relation between yield stress and the blending ratio of MHZ to SHJ crude oil for the compounds at 1℃ are shown in Fig.6, which indicates that the yield stress reduces with the content of MHZ crude oil increasing, especially when its ratio of MHZ to SHJ oil reaches 1:1, the yield stress decreases sharply. As oil temperature drops to a certain extent, the waxes in the compounds will crystallize and disperse in the oil phase in a form of solid particles gradually and may form a gel-shaped or net-like structure. As MHZ oil is added into SHJ oil, the gel-shaped structure strength of the compounds at low temperatures will be weakened, and its yield stress will also be reduced because MHZ crude oil has a lower wax content.

When MHZ crude oil in the compounds increases to some extent, the number of wax crystals is not enough to form a net-like structure at low temperatures. With the mixed MHZ crude oil increasing further, the reduction trend of yield stress is weakening. That is to say, when the blending ratio of MHZ to SHJ crude oil exceeds 6:1, the effect of MHZ crude oil on the yield stress reduction of the compounds is inapparent.

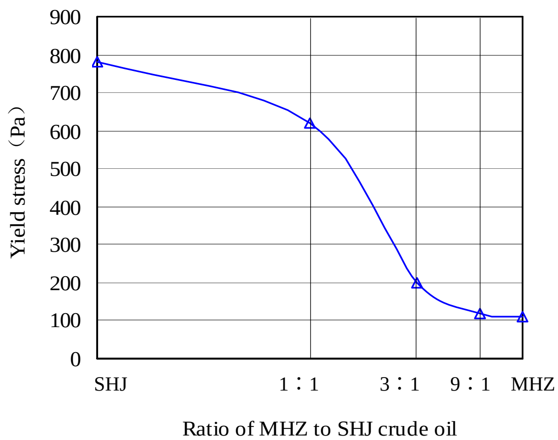


Fig. 6 Relation between yield stress at 1℃ and blending ratio of MHZ to SHJ oil

Thermophysical Properties

The above analyses show that the compounds of the two crude oils can observably change their physical properties and wax crystallization process. How about their thermophysical parameters? Actually, the thermophysical parameters of the compound oils directly affect heating rate, heat radiation, cooling rate, temperature drop law and safe restarting after shutdown of the submarine pipelines. They were measured by CBORI (Chinese Bohai Oil Research Institute) on the above mentioned ASTM standards (Table 1), and the results are listed in Table 5, which can be used to develop the production and blending transportation plan of the two crude oils.

Table 5 Thermophysical properties of crude and compound oils

Oil sample	MHZ	M9S1	M3S1	M1S1	SHJ
Thermal conductivity（W/m·℃）	0.1050	0.1575	0.2130	0.2405	0.1573
Specific heat（J/g·℃）	1.6584	1.7310	1.7767	1.8841	2.0210
Thermal diffusivity（m^2/h）	0.000238	0.000347	0.000464	0.000514	0.000326
Thermal capacity（kcal/m^3·℃）	379.4	390.4	395.3	402.9	415.3
Thermal Value（cal/g）	10516	10553	10556	10615	10629
Latent heat（J/g）	2.03	3.76	5.63	10.28	17.53

It can be seen that thermophysical parameters such as thermal conductivity, latent heat of wax crystallization and thermal diffusivity for the compound oils all increase with SHJ crude oil increasing. For MHZ crude oil, its thermophysical parameters have been improved by blending with SHJ oil, which is unfavorable to insulate against heat during transporting or storing the compounds. But their thermal values also increase correspondingly, which is helpful to improve burning efficiency and sale price.

Moreover, the latent heat of wax crystallization of the oils shows that the waxes crystallized from MHZ crude oil may be composed of macromolecular paraffins, while those from SHJ crude oil may be smaller molecular paraffins. Therefore, different paraffin removers or inhibitors should be chosen for the two crude oils and their compounds.

Recommended Blending Ratio

The reasonable compound ratio of MHZ to SHJ crude oil should be determined by synthetically evaluating the above physical and thermophysical properties, mainly including WAP, yield stress, pour point, viscosity at 50℃ and thermophysical parameters. In order to discuss the problem clearly, the major properties of the oils are summarized in Table 6.

Table 6 Effect of SHJ oil content on physical properties of its compounds

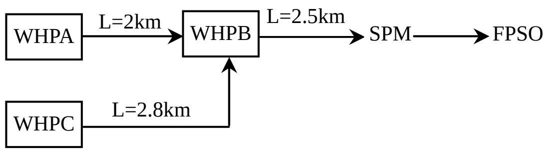
Oil sample	SHJ content (wt%)	Viscosity (mPa.s, 50℃)	WAP(℃)	Pour point (℃)	Yield stress(Pa)
MHZ	0	638.40	-	－11	110
M9S1	10	316.20	42	3	120
M3S1	25	128.40	46	8	200
M1S1	50	40.14	50	17	620
SHJ	100	8.41	51	28	780

Thus it can be seen that the viscosity of the compound oils reduces with the content of SHJ crude oil increasing but all the other parameters increase gradually. When its content reaches 50%, WAP of the compound oil gets close to that of SHJ oil. The transport temperature of the compounds must be elevated in order to avoid the wax deposition due to the increased WAP. The increased pour point and yield stress will make restarting the oil pipeline after shutdown more difficult. But if the mixing amount of SHJ oil is too little, the viscosity of MHZ heavy oil could not be reduced to a pumpable degree. According to the above synthetical analyses, it is appropriate for the ratios of MHZ to SHJ crude oil to be controlled between 2:1 and 7:1.

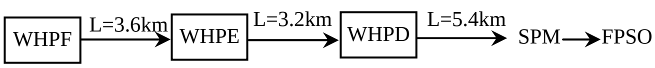
However, it still need to consider other factors such as pipeline length, benthal conditions, topography, environment, existing facilities, dehydration capacity and power supply to determine the reasonable blending ratio for the production and transportation of the two crude oils. A comprehensive economic evaluation on the transportation energy consumption and dehydration cost for different blending ratio should be carried out, and a multivariant synthetic technical and economic comparison should be done to decide the optimum blending ratio and apply it to the production and operation management of the oilfield.

Field Application

The fluids produced in WHPA of BZ25-1 oilfield are all from SHJ block, and those produced in WHPB and WHPC are from both oil blocks, i.e. SHJ (bathypelagic zone) and MHZ (superficial layer). The fluids produced in WHPA and WHPC are transported to WHPB in parallel, and then their mixed fluids flow to SPM and FPSO (Floating Production Storage and Offloading), which is shown as follows:



The fluids produced in WHPD, WHPE and WHPF are all from MHZ block. They are mixed and transported in series to SPM and FPSO, which is shown as follows:



The current daily output and blending ratio of the two crude oils in BZ25-1 oilfield are listed in Table 7, which indicates that all of the blending ratios of the two crude oils in the blending transportation pipeline segments are within the recommended one of 2~7:1, any incompatible problem has not appeared in the submarine pipelines and process facilities up to date, and the production and transportation system of the oilfield functions smoothly. This fully demonstrates that the above recommended blending ratio is reasonable and practicable.

Table 7 Current Output and blending ratios of two crude oils

Platform	SHJ output (m^3/d)	MHZ output (m^3/d)	Subsea pipeline segment	Ratio of MHZ to SHJ
WHPA	398.5	0	WHPC-WHPB	5:1
WHPB	195.0	626.3	WHPB-SPM	2.1:1
WHPC	195.0	1010.7	SPM-FPSO	5.3:1

CONCLUSIONS

- The results of rheological test and NIR scanning have confirmed that the compound of MHZ and SHJ crude oils within the studied blending ratios is completely compatible, and they can be uniformly mixed and keep a stable state for standing a certain time.
- All of the densities, viscosities, acid numbers, asphaltene, resin and sulphur contents of the compound oils increase with the blended MHZ crude oil growing, but their wax contents and pour points perform an opposite trend.
- The thermophysical parameters of the compounds have been enhanced with the blended SHJ crude oil increasing, which is unfavorable to insulate against heat during their transportation and storage due to higher energy consumption. But the thermal value also increases correspondingly, which is useful for the sale of the compounds.
- Based on the physical and thermophysical properties of the compound oils and the field application, a reasonable and practicable MHZ/SHJ blending ratio of 2~7:1 can be concluded, which can meet the safe and economical requirements of the submarine pipelines and facilities.

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