A new experimental method to prevent paraffin–wax formation on the crude oil wells: A field case study in Libya

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Abstract

Wax formation and deposition is one of the most common problems in oil producing wells. This problem occurs as a result of the reduction of the produced fluid temperature below the wax appearance temperature (range between 46 and 50 °C) and the pour point temperature (range between 42 and 44 °C). In this study, two new methods for preventing wax formation were implemented on three oil wells in Libya, where the surface temperature is, normally, 29 °C. In the first method, the gas was injected at a pressure of 83.3 bar and a temperature of 65 °C (greater than the pour point temperature) during the gas-lift operation. In the second method, wax inhibitors (trichloroethylene–xylene (TEX), ethylene copolymers and Comb polymers) were injected down the casings together with the gas. Field observations confirmed that by applying these techniques, the production string was kept clean and no wax was formed. The obtained results show that the wax formation could be prevented by both methods.

Keywords: pour point temperature, wax appearance temperature, chemical inhibitors, gas-lift.

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Paraffin and/or waxes are alkanes, long-chain compounds which separate out from the crude oil when their temperature drops below 46 and 50 °C, forming wax deposition. Without an effective control, the wax deposition could increase substantially with time, causing low productivity and blockage in the tubing string [1,2]. At temperatures lower than the wax appearance temperature (WAT), crystals of wax will form either in the bulk fluid or on cold surfaces where they will build up, consequently, fouling the surface [3––5]. The wax appearance temperature (WAT) or cloud point is the temperature at which wax starts to emerge from the solution as the crude oil is cooled at the atmospheric pressure. Pour point refers to the temperature at which the petroleum fluids stop flowing when the vessel is inverted for up to five seconds [6,7].

Gas-lift wells require low gas-lift rates, which result in low pressure in the casing and this often causes cold flow of the produced fluid [8,9]. Sometimes, the cold flow leads to wax formation and deposition in the production strings, and the financial consequences could be enormous [3,10].

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Typically, for modest crude producers, injection of a small quantity of gas lowers the pressure and, consequently, lowers the temperature of the injected gas to the temperatures which may be lower than the bottom hole temperature [6,9]. In addition, it also makes the temperature of the lifted crude to drop lower than the pour point temperature on the surface. As a result, the tubing ends-up is blocked, and this significantly reduces the flow of the produced crude to the surface [11,12].

Problem statement

Production wells are designed to lift the crude oil using low pressure in the casing side which results in cold flow of the extracted fluid. The recommended injection pressure of the gas ranges from 77.22 to 82.74 bar. Nonetheless, an oil production well of lower capacity requires a small volume of gas to lift their fluid, and in this case, a gas chock is installed in order to control the volume of the gas injected into the gas-lift well. When gas flow is choked, the pressure drops and as a result, the temperature of the gas flowing down the casing also drops. Reduction in the temperature at the surface of the casing results in the cooling of the gas at the casing. This reduction of the gas temperature becomes larger for deeper wells. Cooled gas reduces the temperature of the lifted oil, sometimes below the pour point temperature at the surface. This condition worsens during winter in countries experiencing extreme weather conditions and it may limit the flow of oil or entirely plug the tubing.

METHODS

In this research, two types of field experiments were conducted on three oil wells in Libya: wells A–C. Experiment No.1 involved testing the effectiveness of injecting gas at pressures higher than the ranges leading to the pour point temperature and WAT to prevent wax formation. The optimum pressure for the gas injection was calculated using a mathematical technique. In the experiment No.2 chemical inhibitors were injected down the casings of wells A–C together with the gas. The temperature of the lifted crude oil cooled down below the WAT and pour point temperature. Trichloroethylene-xylene (TEX) was injected into well A; ethylene copolymers were injected into well B and comb polymers were injected into well C.

Experiment No. 1

This experiment involved testing the effectiveness of injecting gas at pressures higher than the ranges leading to the pour point temperature and the wax appearance temperature (WAT), to prevent wax formation. This technique was applied in three oil wells in Libya, wells A–C, which are low oil production wells. They are also low pressure/low temperature wells (LPLT), and, therefore, the gas-lift technique is extensively used to produce oil [9]. The gas was injected into the three wells at a temperature of 65 °C which is above both the WAT and pour point to prevent deposition of wax in the production strings. Observation was carried out every day for 14 days.

Table 1 illustrates a percentage of wax deposition in the production strings of the three oil wells prior to using the new technique. Also, Table 1 shows the production per day, bubble point pressure, previously used pressure, and maximum possible production per day of oil wells A–C.

Experiment No. 2

This experiment involved testing the effectiveness of injecting chemical inhibitors down the casing together with the gas to keep the tubing clean. Without the use of chemical inhibitors, wax starts to deposit in the production string once the temperature at the casing surface drops below the WAT (Figure 1) and a further drop in the temperature leads to an increase of wax deposits, making the tubing very unclean, and this significantly disrupts the flow of crude oil to the surface [11,12].

In this experiment, chemical inhibitors were injected down the casings of wells A–C together with

Table 1.Percentage of wax deposition in the production strings of the wells before using the new method

Well	Pressure bar	Bubble point pressure, bar	Temperature of the surface casing, °C	WAT, °C	Pour point °C	Production m^3/day	Maximum possible production from well, m^3/day	Wax deposition in production strings, %
A	60.673	234.421	33	46	42	71.55	302.1	95
B	62.052	234.421	35	48	43	79.49	286.2	80
C	65.500	234.421	37	50	44	87.45	270.3	57
Average	62.742	234.421	–	–	–	79.49	286.2	–

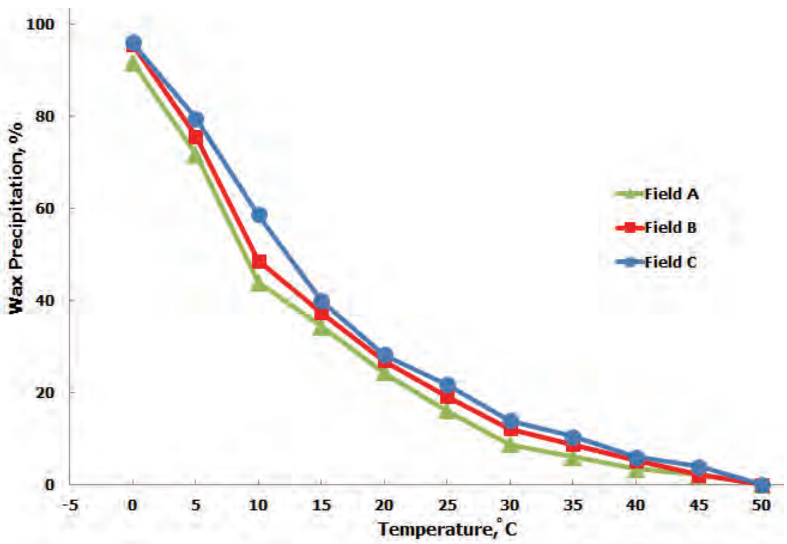

Figure 1.Percentage of wax deposition with temperature of casing before the injection of chemical inhibitors.

the gas. Trichloroethylene-xylene (TEX) was injected into well A; ethylene copolymers were injected into well B and comb polymers were injected into well C. The temperature of the crude oil was then reduced below the WAT, and pour point temperature to determine whether the chemical inhibitors reduced the temperature at which wax crystals begin to form. Sampling of the crude oil was then carried out every day for 14 days at the wellhead for each of the three oil wells.

Determination of optimal pressure for injection

Vogel's equation was used to calculate the optimum injection pressure [13]:

$$\frac{q_x}{q_{x(\max)}}=\left[1-0.20\left(\frac{p_{wf}}{pr}\right)-0.80\left(\frac{p_{wf}}{pr}\right)^2\right] \quad (1)$$

where x = O (oil, in case of oil), L (liquid, in case of liquid production, oil + water), q_x = measured stabilized productivity surface flow rate, $q_{x(\max)}$ = maximum production rate at the maximum drawdown, P_{wf} = 0, P_{wf} = measured stabilized flowing pressure in the wellbore and *pr* = average reservoir pressure.

This equation is applicable to any reservoir in which gas saturation increases as pressure decreases. Also, it could be applied to wells with a water cut, since the increasing gas saturation will concomitantly reduce the permeability to water. This approach has been used successfully for wells with water cuts up to 97% [13]. The equation provides the optimum pressure which is required to produce oil without wax formation, as well as the optimum pressure that maximizes the well potential in terms of production of barrels per day. The calculation of optimum injection pressure was, according to the Eq. (1), and it was found to be in the ranges (from 83.0 to 86.3 bar). It is worth noticing that, this equation has previously been used for the same calculation by Caicedo [14].

According to the results obtained from this calculation, gas under pressure of 68.95, 79.29 and 83.3 bar were injected into the tubing's of wells A–C respectively to create pressure in the wellbore and lift the crude oil to the surface.

RESULTS AND DISCUSSION

Effect of injected gas pressure

The results obtained from experiment No.1 showed that a significant wax deposition was observed in the production string for well A. The main reason for that result is the low injected gas pressure of 68.94 bar, which led to a drop in the injected gas temperature down the casing. Consequently, the temperature at the surface of the casing was lowered, cooling down the temperature of the lifted crude to 39 °C which is below the pour point temperature, causing wax to form within the production string.

For well B, a relatively small amount of wax deposition was observed in the production string. Even though the gas was injected into the tubing with comparatively high pressure of 79.29 bar, this pressure was not high enough to prevent the formation of wax crystals in the production string. The temperature of the casing dropped to the point at which the injected gas temperature was 42 °C (below the WAT and pour point temperature), which resulted in wax deposition, but the wax deposition was not as much as observed in a well A. As For well C, no wax deposition was observed in the production string.

The previous findings indicate that the injected gas pressure of (83.29 bar) was sufficiently high to provide the appropriate temperature of the gas injected down the casing. As a result, the temperature of the produced crude oil on the casing surface was around 55 °C, which was higher than the pour point temperature and WAT, so no wax deposition was formed in the production string.

Table 2 illustrates a percentage of wax precipitation in the production strings for the three wells after using this new method with optimal pressure for wax formation prevention. From these results, it can be concluded that using gas pressures as high as (83.3 bar) in the gas-lift technique, is effective in lifting the oil from the wellbore to the surface without the formation of wax in the production strings.

Effect of chemical inhibitors

Figure 1 represents a percentage of wax deposition with temperatures of casing before the injection of chemical inhibitors. It is clear from Figure 1 that wax starts to deposit in the production strings once the temperature at the casing surface drops below 50 °C,

Table 2.Percentage of wax precipitation after using the new method with optimal pressure

Oil well	Pressure/temperature bar/°C	Pour point, °C	WAT, °C	Temperature of the surface casing, °C	Wax deposition in production string, %
A	68.95/65	42	46	39	10
B	79.3/65	43	48	42	5
C	83.3/65	44	50	55	Less than 2

the WAT, and a further drop in temperature leads to severe increase of wax deposits.

The results obtained from experiment No.2 are illustrated in Figure 2 and Table 3. Figure 2 represents a reduction of wax deposition percentage with temperatures of casing after the injection of chemical inhibitors. The results indicate that, the temperatures at which wax began to deposit in the tubing were reduced significantly after the injection of chemical inhibitors down the tubing together with the gas. It can be also seen from Figure 2 that no wax was formed after injecting the chemical inhibitors for the three oil wells even at the temperature of 30 °C, as compared to 50 °C in the case without injecting the chemical inhibitors.

Table 3 shows a percentage of wax precipitation at 0°C before and after the usage of chemical inhibitors at a temperature of zero degrees Celsius (0 °C). Table 3 shows that the percentage of wax precipitation was reduced to half its value after the usage of chemical inhibitors at a temperature of 0 °C.

Although three different types of chemical inhibitors were used in these experiments, they were effective in reducing the amount of wax deposition in the tubing with the reduction in the temperature of the crude oil. These results may be explained as follows: The chemical inhibitor TEX is made up of structures with sections, interact with the forming wax crystals and prevent its growth, keeping the tubing clean [15–17]. Ethylene copolymers and Comb polymer's chemical inhibitors are imperative in preventing gelling and/or wax deposition in pipelines. This is primarily because they alter the wax crystals in order to prevent them from agglomerating and depositing, and thus keeping the tubing clean [18–20]. Moreover, all TEX, ethylene copolymers and Comb polymers are wax crystal modifiers which attack the nucleating agents of the wax deposits, breaking it down and preventing paraffin crystals from agglomerating [21]. This has also been explained to result from their ability to keep the nucleating agents within the solution [22,23].

The results obtained from the experiment No.2 show that injecting chemical inhibitors down the casing together with the gas offer potential solutions to the problem of wax deposition in oil wells employing the gas-lift technique.

CONCLUSION

Based on the results obtained, it can be concluded that wax deposition in oil producing wells can be prevented during the gas-lift operations by two methods. The first method is injecting the gas at a

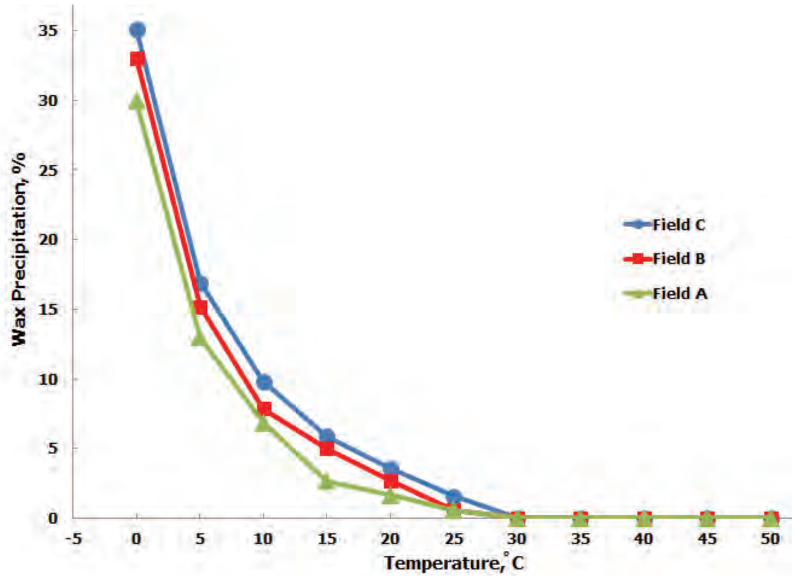

Figure 2.Reduction of wax deposition percentage with temperature of casing after the injection of chemical inhibitors.

Table 3.Percentage of wax precipitation at 0 °C before and after the injection of chemical inhibitors

Oil well	Pour point, °C	WAT, °C	Wax deposition in the production strings			
			Before		After	
			Temperature, °C	Wax deposition, %	Temperature, °C	Wax deposition, %
A	42	46	0	94	0°	30
B	43	48	0	96	0°	33
C	44	50	0	98	0°	35

pressure of (86.3 bar) which results in a surface casing temperature above the wax appearance temperature and the pour point temperature (52 °C). The second method is injecting chemical inhibitors with the gas down the casing. In this method TEX, ethylene copolymers and comb polymers have been used and have proved effective in reducing the wax formation temperature, thus enabling injecting the gas at lower pressures. The method selection should be based on economic estimations.

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IZVOD

NOVA EKSPERIMENTALNA METODA ZA SPREČAVANJE FORMIRANJA PARAFINSKIH NASLAGA–VOSKA NA NAFTNIM BUŠOTINAMA: STUDIJA NA NAFTNIM POLJIMA U LIBIJI

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(Stručni rad)

Formiranje i taloženje parafinskih naslaga je jedan od najčešćih problema na naftnim bušotinama. Ovaj problem se javlja usled opadanja temperature nafte ispod temperature formiranja voska (između 46 i 50 °C) i temperature tečenja (između 42 i 44 °C). U ovom istraživanju dve nove metode za sprečavanje formiranja naslaga parafina su primenjene na tri izvorišta nafte u Libiji, gde su normalne temperature okoline 29 °C. U prvoj metodi se gas prilikom ispumpavanja nafte ubacivao pod pritiskom od 83.3 bar i temperaturom od 65 °C (veća od temperature tečenja). Druga metoda se sastojala u ubrizgavanju sredstava za rastvaranje parafina (trihloroetilenksilena (TEX), etilen kopolimera i comb polimera) u bušotinu zajedno sa gasom. Istraživanje je pokazalo da je primenom ovih tehnika bušotina bila čista i bez naslaga parafina. Ovi rezultati pokazuju da se formiranja naslaga parafina može sprečiti ovim metodama.

Ključne reči: Temperatura tečenja • Temperatura formiranja voska • Hemijski inhibitori • Gas lift