CONTROL OF PARAFFIN DEPOSITION WITH WAX INHIBITORS

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INTRODUCTION

When paraffin is deposited from crude oil on downhole and surface equipment, it can reduce oil production and increase maintenance costs. Paraffin may deposit in tubular goods as a hard coating that gradually decreases flow capacity of lines and producing capability of wells. Paraffin crystallized from solution may be trapped at restrictions (beans, valves, controllers) and cause complete or temporary plugging of the system. Pressure surges caused by intermittent plugging and extrusion of the paraffin can overload pumps, flood the separators, and may result in equipment failure.

Mechanical and thermal methods have been most widely used to remove wax deposits. Although chemical inhibition has often seemed to offer promise of preventing wax deposition and reducing operating costs, field trials of commercial products by our operations people were generally unsuccessful. The purpose of this paper is to report on the development and field testing of a new wax inhibitor which has been used successfully and economically in hundreds of wells.

HISTORY

The basic properties and the chemistry of paraffin, as defined by previous investigators, are extremely enlightening, and aid in understanding the physical behavior of wax in crude oils.

In 1955, Shock et al[1] of Continental gave a good description of the deposition of paraffinic components from crude oil. They observed that paraffin differs from most components of crude oil in that it is simply a straight-chain hydrocarbon. Paraffin ranges from low to high molecular weight; the liquid paraffins are less than 216 MW ($C_{18}H_{38}$ or less), whereas the solid paraffins are over 216 MW ($C_{18}H_{38}$ to $C_{38}H_{78}$). The solids are simple crystalline products. In 1962, Knox et al[2] showed that crystal behavior is the paraffin property that causes trouble. Paraffin separates from crude oil as an amorphous solid which, with time, agglomerates as a cluster of individual crystals. The same authors later showed that, to inhibit paraffin deposition in crude oil, this tendency to crystallize must be reduced, even to the point of preventing the formation of individual crystals.

In 1932, Reistle[3] reported a most interesting phenomenon relating to the effect of paraffin upon the pour point of the crude oil. The high pour point of crude oil is caused by paraffin crystals forming an interlocking network.

In 1966, Jorda[4] determined by empirical means that the adhesion of paraffin to metal is a function of the roughness of the metal surface. He concluded that the rougher the surface, the greater the paraffin deposition, the harder the deposit, and the more the adhesion of the paraffin to the surface.

In 1951, Ruhrwein[5] gave a very important answer to the problem of depressing paraffin crystal structure in crude oils. Effective suppression of such crystallization can be brought about by causing coprecipitation of paraffin with an inhibitor.

In summary, it was concluded that:

1. The physical properties of paraffinic crude oils are strongly influenced by crystallization of paraffin components.

2. The wax inhibitor must prevent crystal formation in order to control paraffin adhesion to metal surface and to prevent increase in viscosity of crude oil.

LABORATORY EVALUATION OF INHIBITORS

Using the theory developed by the earlier experimentalists, we first devised a simple static test that would emphasize the crystal behavior of paraffin in oil. Work was carried out with 12-in. long by 1-in. diameter tubes maintained at a 60° angle with vertical. The tubes were filled with fluid, both compounded with inhibitor and uncompounded, and were allowed to stand at 35°F for 24 hours. The fluidity was observed and recorded. Simultaneously, the standard ASTM pour point was determined on duplicate samples.

To aid visual observations, a simulated crude oil was formulated that provided a reproducible standard. The solubility of paraffin wax in 18 to 40 gravity crude oils is similar to its solubility in this simulated crude oil, a mixture of 70% by volume kerosene and 30% by volume 90 neutral oil. Paraffinic test fluids were prepared by dissolving 3% of a given paraffin in the simulated crude oil. These fluids were then compounded with 2000 ppm inhibitor, the first inhibitors tested in the laboratory being commercially available products. Most of them had been field tested and found ineffective.

Inhibitor screening was extended to include a large assortment of organic wetting agents, detergents, polymers, and synthesized polymeric components. Of the many compounds tested, only one polymer family was found that prevented paraffin crystallization in the laboratory tests. This combination we have called NO-WAX INHIBITOR.[6] The more specific tests described below were all carried out with this particular inhibitor.

It was found that the effectiveness of NO-WAX INHIBITOR on all paraffinic crudes, simulated or natural, depended on four factors:

1. The kind of paraffin in the crude oil
2. The concentration of the paraffin in the crude oil
3. The solvent base of the crude oil
4. The amount and type of inhibitor used.

In additional studies we measured the deposition of paraffin from paraffinic crude oils with several different dynamic tests made. Comparisons were based on deposition of paraffin from a circulating fluid on a cooled surface, such as a flat plate[4] or the interior of a steel pipe inserted in the circulating system. Flow rate was kept constant. In this series of tests, paraffin deposition was found to be related to the melting point of the paraffin and to fluid temperature; but it was concluded that dynamic laboratory tests offered little useful indication of inhibitor activity.

PRE-FIELD LABORATORY TESTS OF NO-WAX INHIBITOR

Before inhibitor treatment is started, crude oil samples are obtained, the total paraffin content of the crude oil is determined, and the relative ability of the paraffin inhibitor to depress pour point is measured. When the paraffin content of a crude oil is above 10%, it is difficult to treat economically. However, if the laboratory pour-point test indicates promise, a field pilot test is initiated.

FIELD TRIALS OF NO-WAX INHIBITOR

Test Criteria

Current tests involve over 100 wells in fields throughout the United States and Canada.

Criteria used to evaluate the inhibitor are wellhead and flowline pressure changes, frequency of hot-oil or mechanical well cleaning, well test data, and maintenance costs.

The field tests reveal that:

1. Most wells respond after one month's inhibitor treatment.
2. Rods, tubing, and pumps pulled from treated wells have been free of paraffin deposit.
3. In some fields, wells produced by rod pumping showed production increases of about 10%.
4. Six wells produced by downhole hydraulic pumps had production increases ranging from 30-50%.

The inhibitor has proven effective when applied at a point in the system where the paraffin is still in solution. The additive should be applied continuously to prevent paraffin from crystallizing and adhering to the downhole and surface equipment. Well treatment carried out in cold weather (less than 10°F over extended periods of time) requires special application procedures. Further tests are being made to improve treatment under these conditions.

Detailed Results

The results of inhibitor treatment in several fields in California, Texas, and Canada are summarized in Table 1. Applications in California have been in progress over three years and are now considered routine operations. Treated wells have operated satisfactorily without evidence of wellhead pressure buildup, loss of productivity, or need for hot oiling of wells or flow lines.

Field 1 is produced with rod pumps. The inhibitor treatment brought about more uniform and increased production from the treated wells. It prevented paraffin buildup in the wells, and cut down the number of pressure surges. Since treatment was started, these wells have required no hot oiling to remove paraffin in either wells or lines. On workover, the wells were found free of paraffin.

In fields 2 and 3, after treatment was started in the six wells equipped with downhole hydraulic pumps, production stabilized and well productivity increased. For the first time the free hydraulic pumps could be pumped to the surface without hot oiling to remove accumulated paraffin. We can now count the hydraulic pump strokes at the wellhead.

Figure 1 illustrates a typical response. Required power oil surface pressure declined, and lead line pressure stabilized. Prior to treatment, these wells had required an average of four hot-oil treatments per year to remove paraffin from tubing and lead lines.

Rod-pumped wells under treatment have exhibited improved performance without evidence of wellhead pressure buildup, loss of productivity, or need for hot oiling of wells or flow lines.

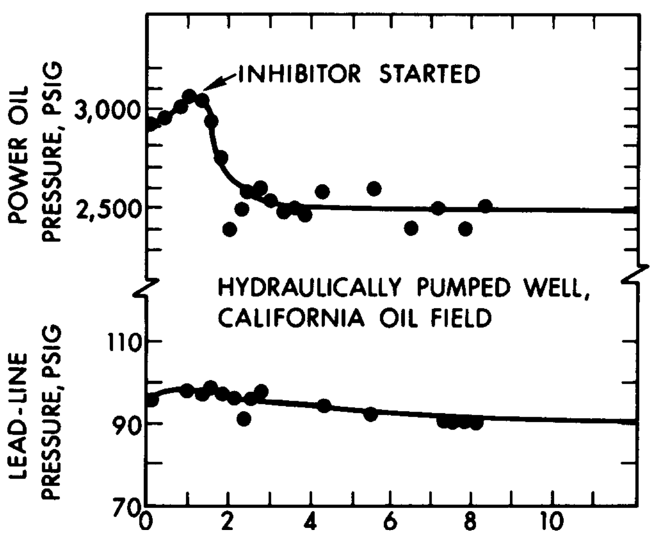

FIG. 1—RESPONSE TO HYDRAULIC PUMPED WELLS, CALIFORNIA OIL FIELD

Before the inhibitor treatment, "pulling the well" required the application of hot oil, then laborious pulling of the pump through heavy layers of paraffin deposits. We think the inhibitor treatment not only prevented additional deposits from forming in tubing, but also removed previously deposited paraffin.

After 18 months of treatment of 30 wells in an offshore location, (all produced by submersible electric pumps and controlled with centralized automated treaters), no paraffin deposits have been observed in storm chokes or surface valves and productivity increased on about 50% of the wells. Prior to start of inhibitor treatments, paraffin deposits interfered with operation of about 25% of the storm chokes and valves and in some cases monthly clean-up was required. Well treatments at this location also helped control wax deposits in the long transmission line to shore. Although the line carries production for many untreated wells of other operators, the amount of wax displaced in pigging was less voluminous and was softer.

Figure 2 shows the effect of application procedures on the gross daily production of one of these offshore wells. From July 1972, to February 1973, the inhibitor was scheduled for daily batch treatment from the annulus. After treatment started, production rate fluctuations smoothed out, and cumulative production per unit time increased. In 1973, an automatic chemical injection system was installed, and within one month a substantial production increase was observed. Thereafter, the decline curve remained about 300 BPD higher than the decline curve with the manual injection system.

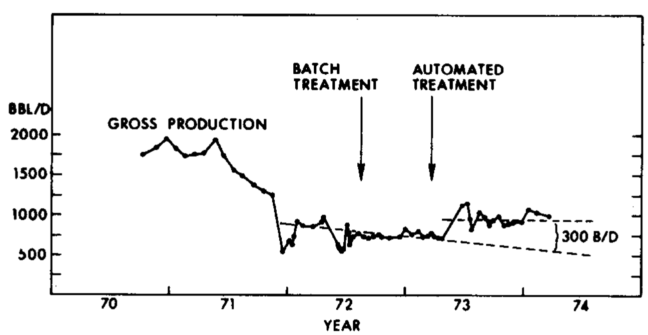

FIG. 2—COMPARISON OF BATCH AND AUTOMATED INHIBITOR TREATMENTS

In five Canadian fields, nine wells were selected as a pilot test of inhibitor treatment. The results from three wells in three different fields are listed in Table 1. The numbers of mechanical scraping treatments required were markedly smaller after the NO-WAX INHIBITOR treatment was started. Field people also reported a reduction in required mechanical treatments for the remaining six wells, but no quantitative data are available. In several cases, previously scheduled routine paraffin-removal treatments were continued after treatment started, and actual well conditions were not checked.

In coupon tests, the paraffin deposits were found to change from hard and dry before treatment to soft and mushy after treatment. Although elimination of all paraffin deposits was not achieved, the reduction in paraffin removal treatments and the change in physical properties of the remaining deposits have justified routine use of the inhibitor.

One well in each of three West Texas fields, was treated with paraffin inhibitor. Reduction of hot-oil treatments of these wells is shown in Table 1. After 12 months, hot oiling was eliminated but there is still a small amount of soft paraffin deposit remaining. To date, the soft paraffin has not been troublesome and has not required additional treatment. The single treatments indicated in fields 10 and 11 were done as part of a routine well-pulling procedure.

HOW THE INHIBITOR IS APPLIED

For optimum performance, proper application of inhibitor is important. Continuous application at a point in the system (usually downhole) where the temperature is above the crystallization point of the paraffin is desirable, if not essential. This does not necessarily mean that complete continuous application at the wellhead is required. Run-down time in the annulus of a well, together with the "fluid over the pump", may be used to extend the effective treating time of a "shot"-type treatment. However, time between injections must not be too long.

TABLE 1—THE EFFECT OF NO-WAX INHIBITOR ON WAXY WELLS

Field	No. of Wells	Type Ring	Hot Oil Treatment Number per Year Before Inhibitor	After Inhibitor	Gross Production, B/D Before Inhibitor	After Inhibitor	Paraffin in Oil, % by wt.	Remarks
			California Fields					
1	7	Rod	28	0	105	114	4.0	Wells worked over. Free of Paraffin.
2	4	Hydraulic	16	0	66	99	4.0	Can now count strokes on hydraulic pump.
2	8	Rod	32	0	86	86	4.0	
3	2	Hydraulic	8	0	207	265	4.0	Stopped heating power fluid.
4	16	Rod	64	0	81	81	4.0	Wells free of paraffin when worked over.
5	35	Rod	140	1	300	300	3.5	Wells free of paraffin when worked over.
			Canadian Fields (Cold Weather Treatments)					
			Mechanized Dewaxing Number per Year					
6	1	Flowing	180	14	122	122	3.8	Wax softened.
7	1	Rod	90	12	112	121	4.7	Wax softened.
8	1	Flowing	70	12	348	415	3.5	Wax softened.
			West Texas Fields					
			Hot Oil Treatment Number per Year					
9	1	Hydraulic	4	0	24	24	--	No paraffin.
10	1	Rod	12	1	65	65	--	Wax softened.
11	1	Rod	12	1	87	87	--	Wax softened.

Two-string hydraulically pumped wells allow the simplest application. The inhibitor is metered directly into the suction of the surface triplex pump. All other types of wells require a means of supplying the inhibitor (usually with a diluent carrier) to some point downhole. The inhibitor may be flushed down the annulus or injected through a macaroni string.

To date, most installations have used the annulus-flush method. Two versions have been developed. In the first, the inhibitor is premixed with solvent or produced oil. In the second, the inhibitor concentrate is metered directly into a flush-oil stream.

AUTOMATED FEED SYSTEM

An automatic central system is a valuable aid when a number of wells can be treated from a single location. A suitable manifold, time-controlled system can sequentially treat a number of wells, using a common feed pump and storage facility. Because the time interval between injections can be kept short, downhole treatment is effectively continuous. Inhibitor diluted with flush oil is used in this system.

Automated operation is used in all the California fields listed in Table 1, except for the hydraulically pumped wells. In the latter case, inhibitor is pumped into the power oil system to take care of dilution by make-up oil.

HEATED SYSTEM

For cold weather application (less than 10°F over extended periods of time, such as occur in Canada), the drum and pump are placed in a small box-like chamber, and the drum is heated with an electrical strap wrapped around it. Also, each well is provided with a line connecting the production flow line to the annulus. With this arrangement, the inhibitor is pumpable on a year-round basis, and small portions can be injected into the annulus. In some cases, a pump capable of circulating about 1-5 BPD crude oil is used to inject the production oil into the well.

ECONOMIC ADVANTAGES

Table 2 shows the savings realized from treating 64 waxy wells in five California fields. Gross cost savings in 12 months were at least $31,000 less $5900 for chemical inhibitor. A modest cost for inhibitor application is not included.

Although the primary objective in the use of paraffin inhibitor is to reduce maintenance cost in hot oiling and mechanical scraping, we have sometimes observed substantial increases in average well productivity. The magnitude of such productivity increases is variable and is not included in the economics, even though production increases up to 50% have been observed. In a few cases, such as shown in Fig. 3, spectacular rises in the level of production decline curves have been observed.

At least two possible explanations may be given for production increases following treatment:

1. Tubing restrictions that result from wax deposition during normal untreated operations may be reduced or eliminated.
2. Inhibitor addition down the annulus may clean deposits from slots or perforations, and thereby stimulate wellbore conductivity.

TABLE 2—ANNUAL COST SAVINGS FROM INHIBITOR

Field	No. of Wells	Hot Oil	Maintenance	Well Crew	Trucking	Total	Inhibitor Cost, $	Net Savings, $
1	7	1,250	4,300	150	750	6,450	650	5,800
2	4	700	1,500	1,000	400	3,600	360	3,240
3	2	400	2,800[a]	0	250	3,450	180	3,270
4	16	2,540	4,250	3,500	400	10,690	1,500	9,190
5	35	4,500	0[b]	2,000	500	7,000	3,200	3,800

a Includes fuel gas no longer needed to heat power oil.

b Comparable costs unavailable because of casing problems on some of the wells.

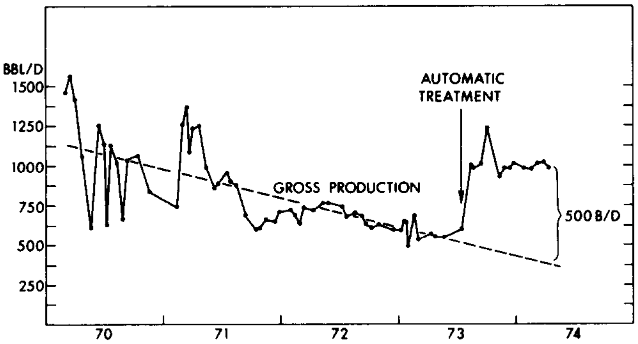

FIG. 3—EFFECT OF INHIBITOR INJECTION IN WELLS WITH DOWNHOLE ELECTRIC PUMP, CALIFORNIA FIELD

Inhibitor is applied continuously at an initial rate of one gal. NO-WAX INHIBITOR per 100 bbl net crude oil. Lesser amounts are often used after wellhead pressures stabilize at reduced levels.

Cost of inhibitor is presently around 1 to 2¢/bbl of treated net oil.

CONCLUSIONS

A new inhibitor, called NO-WAX INHIBITOR, has been developed to prevent wax deposition on rods, tubing, pumps and surface equipment. Field tests in over 100 wells have demonstrated that hard paraffin deposits are either eliminated or changed to a soft, low-strength material that does not interfere with operating equipment. Pressure surges caused by intermittent plugging of lines is eliminated and need for hot-oil or mechanical treatment has been eliminated in most cases. Costs of well treatment have been reduced.

In some fields, wells produced by rod, hydraulic, or downhole electric pumps have shown production increases.

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