A REVIEW OF PAST 50 YEARS OF PARAFFIN PREVENTION AND REMOVAL TECHNIQUES AS PRESENTED IN THE SWPSC

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ABSTRACT

Paraffin related problems in the oilfield continue to hamper efficient production operations. Over the years, many thermal, chemical and microbial techniques have been developed for paraffin removal and inhibition. But it is very difficult to decide which treatment process will be the most efficient in a given environment. Only an experienced person with a vast knowledge of previous treatment operations can give a suitable decision. This project aims at making a comparative study of these techniques with an objective of creating a decision tree to diagnose and suggest the best remedial measure for such problems.

MECHANICAL TREATMENT METHODS

Before the 1950's, more importance was given to removal of paraffin deposition rather than prevention of paraffin formation. One of the mechanical methods for paraffin removal from the production tubing was based on using the wire-line scraping tool." The wire-line scraping device is equipped with the knife-edge cutters which could thoroughly scrape the paraffin deposits from the inside surface of the tubing string while pulling the wire-line tool up through the tubing.

In the 1950's, a device called a "rabbit" was available in the market for commercial use. A rabbit is a mechanical scraping device, which is dropped down through the tubing string while well is in shut-in condition." It is allowed to fall down freely to the stop ring, placed below the bottom level of paraffin deposits in the tubing string. The diameter of the rabbit gets bigger as soon as it hits the stop ring. After the well production is resumed, the well fluid pressure pushes the rabbit up back towards the wellhead. Paraffin deposits are scraped from the tubing wall by cutting edges of the rabbit and carried up to the surface with the produced fluid. Once the rabbit reaches to the top, it is retrieved out from the wellhead.

Another effective mechanical method, available for paraffin removal from tubing strings and flow-lines, was the use of soluble plugs.". [56] One of the advantages of soluble plugs was their tendency to dissolve in the crude oil after the paraffin treatment operation. Therefore, the need to recover these paraffin-cutting plugs was eliminated. Soluble plugs had strength enough to clean the paraftin accumulation from the inside walls of the tubing string and tlow-lines by applying a fluid pressure behind the plug. A variety of different diameter soluble plugs were available for several tubing and flow-line sizes. Because the use of soluble plugs was not an expensive operation, Ward" recommended using soluble plugs frequently to prevent a large paraffin accumulation. For cultivated areas, where all the flow-lines with low flow rate were installed below the ground surface, Snedeker[56] emphasized more on running soluble plugs on a strict schedule to clean flow-lines from paraffin deposits.

The oil industry was introduced with a new technology for paraffin removal from rod pumped wells by using rod type paraffin scrappers. According to Young," the rod scrappers gained popularity between 1946 and 1950. The Huber rotating flat blade, triple horn spiral, sunshine continuous spiral, and crall type spiral were the most popular types of the sucker rod paraffin scrappers.

With the advent of hollow sucker rod string, heat loss to the well-bore surrounding formation was considerably reduced." " Hot oil was injected down to the tubing through the hollow rod string. The hollow rod had a check valve at its bottom end. After the injected hot oil reaches the check valve, it enters to the tubing string and further flows down to the bottom of the well-bore to melt and dissolve paraffin deposits from the tubing wall. Ward[55] recommended using hollow rod string in high paraffin producing fields because of high installation costs as compared to conventional ***rod*** installations.

THERMAL TREATMENT METHODS

The hot oiling or watering method gained wide acceptance for paraffin deposit removal because of its simplicity in application, low cost to accomplish treatment jobs, and immediate paraffin treatment results. According to Snedeker,[56] the hot oiling and steaming were two of the most common thermal methods for paraffin deposit removal in the rod pumped wells. Steam or crude oil with a temperature approximately 300°F were injected into the annular space between the tubing string and casing. This technique allowed the injected steam or hot oil transferring heat to the paraffin deposits, accumulated on the inner surface of the tubing string, through the tubing walls and thus softening and dissolving the paraffin into the produced formation fluid. Paraffin melts and dissolves in the tubing fluid and carries up to the surface with produced formation fluid.

However, there were many disadvantages in using this method which had been ignored during the past years of paraffin removal operations.[59-61] One of the disadvantages in hot oiling operations was the composition of the source oil used for paraffin treatment operations. It was a general practice to draw source oil for hot oiling from the bottom of the storage tanks, located near the paraffin treatment wells. These storage tanks usually contained crude oil with high quantities of paraffin contents, as the produced oil coming to these storage tanks was usually from the same wells that were to be treated for paraffin deposits removal.

At the surface pressure and temperature conditions, paraftin and asphaltic components of the crude oil have a greater tendency to precipitate and settle on the bottom of the storage tanks. Crude oil with paraffin content oil is heated and pumped down to the well-bore for paraffin removal. It starts losing heat to the walls of the tubing, casing, and fluid produced by the formation. By the time injected hot oil reaches the bottom of the annular space between casing and tubing string, it can loose enough heat to precipitate paraffin deposits, present in the injected hot oil itself. In addition, light hydrocarbons vaporize from the injected hot oil and cause the loss of oil from the hot oil. Such light hydrocarbons, escaped from the injected hot oil, travel up to the wellhead as a gas and cause an increase in the percentage of paraffin in the remaining hot oil. Such increase of paraffin's percentage in the injected oil raises the cloud point and thus, causing paraftin precipitation in the injected hot oil at relatively higher temperature.

Injection of high paraffin content hot oil and the loss of light hydrocarbons causes severe damage to the producing formation by plugging the face of the formation with paraffin, precipitated from the injected hot oil and formation fluid near the bottom of the well-bore. This happens when the hydrostatic pressure, applied by the fluid column in the annulus near the bottom-hole area of the well-bore, becomes greater than the formation pressure and fluid column exerts pressure on the injected hot oil near the producing formation. This pressure forces the hot oil with precipitated paraffin content to invade into the producing formation face.

Herman et al.[59-61] recommended the following possible solutions to the disadvantages of using high paraffin content oil:

- Use of oil from the top of the storage tanks as the source oil for hot oiling operations.
- Periodical clean up of the producing formation face.
- Use of chemical dispersants in the source oil to prevent paraffin precipitation from the injected hot oil itself.
- Use of other available fluid (low salinity water) as a source injection fluid.

Oil field operators were also successful in removing paraffin deposits from the face of the producing formation by using different expensive techniques such as explosive shots of nitroglycerine, down-hole electrical heaters, and heat-generating chemical reactions that heat up and dissolve paraffin deposits from the producing formation face. The importance of direct heat of the sunshine was also considered as one of the available methods for controlling paraffin deposition in the flow-lines, laying on the surface.[56]

Recently, a novel method was introduced to the oil industry for paraffin wax and asphaltene removal by generating an exothermic reaction.[12] The reaction process was reported to be non-aqueous and produced a paraffin dispersant as a reaction by-product that prevented re-deposition of dispersed paraffin in the treated fluid at normal temperature. One of the advantages of non-aqueous based exothermic reaction was to prevent the formation of water/oil emulsion while treating crude oil for paraffin removal. The process of the exothermic reaction involved generation of heat by mixing an organic acid compound with an organic base compound or inorganic base on the surface and pumping the mixture through the tubing to generate temperature enough (>212 "F) to melt and disperse paraffin wax and asphaltene deposits. A number of solvents were available to carry the reactants to the paraffin affected area in the production zone. After the treatment well was shut-in for 20-40 minutes, pumping the injected fluid back to the surface retrieved melted or dispersed paraffin wax and asphaltenes. Brown and Dobbs[12] stated three major advantages of using exothermic method for paraffin removal:

- Sufficient heat release to melt paraffin deposits.
- Excellent behavior of reactant-carrier solvent at elevated temperatures.
- Complete removal of paraffin affected lines due to produced paraftin dispersant from in-situ exothermic reaction.

CHEMICAL TREATMENT METHODS

Before the second half of the 20th century, most of the paraffin removal jobs were accomplished by mechanical means only.[63] Use of mechanical methods to prevent or remove paraffin accumulation became economically prohibitive with the advent of offshore production technology. It became necessary to use chemical methods for paraffin build-up inhibition or removal.''

Chemical solvents were used as a paraffin softening agents to break up or soften accumulated paraffin into small and soft paraffin particles from the inside surface of the production and transportation lines so that produced formation fluid could flush the dispersed paraffin particles along the line. For softer paraffin deposits (composed of lighter paraffin hydrocarbons), a mixture of white gasoline or kerosene with chemical solvents was frequently used to treat such deposits.'' The type and amount of the paraffin deposits were the two major deciding factors for the volume of solvent to be used for paraffin treatment purpose. McKinney[58, 75] recommended obtaining a paraffin sample from the troublesome wells with paraffin accumulation problem and testing the sample in different chemical solvents to find the best solvent available to treat the well. For cleaning flow-lines with severe paraffin deposition, a small amount of solvent was suggested to flush through the line to gradually remove paraffin without clogging the flow-lines followed by pumping larger volume of solvent along the flow-lines.

Chemical treatment of wells with paraffin problems required frequent injection of chemical solvents in the annular space between tubing string and casing to mix with the crude oil in the bottom of the hole. Continuous injection of paraffin inhibitors into the well casing and surface lead lines was often reported to minimize build-up and accumulation of paraffin crystals in the produced formation fluid. Use of an efficient chemical solvent of chlorinated type, namely carbon tetrachloride, caused severe corrosion problems in many production facilities and consequently was banned by the government for use in the oil fields.[65] At the same time, carbon bisulfide was widely accepted as an efficient chemical solvent for paraffin inhibition. Extreme care was recommended in handling carbon bisulfide because of its potential to quickly react upon exposure to flame.

Reduction in hot oiling operations was achieved with the development of systematic squeeze treatment technique. According to Brock,[60] the squeeze treatment method was tested on two of the producing wells in Test Lease No.3 in Spraberry Formation, West Texas, in June 1983. Before squeeze treatment operation, hot oiling method was practiced on both of the test wells to prevent paraffin accumulation on the producing formation face and the tubing. The squeeze treatment was performed by mixing 25 barrels of crude oil with one drum of chemical (dispersant), pumping the mixture into the annulus, and flushing the annulus with 150 barrels of produced water at a controlled pumping rate not exceeding 2.5 barrels per minute. After the squeeze treatment, it was reported that none of the test wells were hot oiled for over one year.

According to Lukehart,[66] a study on the paraffin deposition mechanism revealed that the key factor behind paraffin separation from the crude oil, under well and flow-lines operating conditions, was the solubility of paraffin in the produced oil. In April of 1956, an experimental butane injection unit was installed on one of the oil producing wells in Carter County, Oklahoma, in an attempt to reduce the paraffin treatment costs. The reason why butane was selected for the injection purpose was because of its availability and cost effectiveness. After two years of successful operation, paraftin control using this butane injection technique saved approximately $2,200 over previous control methods on that particular well. In general, the frequency and amount of butane injection was dependent upon surface temperature conditions. Oil operators were able to reduce the paraffin control cost as much as 90 percent over hot watering that was previously practiced on this well for paraffin control.

In an attempt to minimize the treatment costs on producing wells with potential paraffin problems, a novel method was tested on one of the producing wells in the Ackerly Dean Unit in the Dawson County, Texas.[67] The technique involved the addition of crystal growth modifier in both solid and liquid forms to the well fracturing fluid. After the successful fracture treatment of the well, no paraffin deposition problem was reported during the next six months. Because the addition of paraffin inhibitor was a one-time job, it allowed for the operators to evaluate economics and choose from the available paraffin deposition control and/or removal methods for the well treatment in future time.

Use of blended and refined condensate feedstock consisting of high multiple aromatic hydrocarbons, became popular for dissolving and/or controlling paraffin and asphaltene related problems.[68] Petroleum distillates were blended and refined to get natural solvents with high solvency, demulsifying and wettability properties. These natural solvents proved to be cost effective and offered enhancement to the other available paraffin treatment methods. One of the techniques to enhance the paraffin treatment by hot oiling or hot watering was to add the natural solvents (10% by volume) to the hot oil or water treatment. According to King and Cotney,[68] "Although condensate should not be injected into the formation it may be economical and practical to use them as flush volumes. Injecting 5% to 20% of the refined natural solvents in front of the condensate treatments can greatly enhance the performance. The condensate will wash all the solvents to bottom and provide a diluting fluid to the paraffin saturated production" (p. 262).

OTHER TREATMENT METHODS

A number of production techniques were practiced in the oil fields to prevent paraffin precipitation. According to Ward,[55] more emphasis was put on paraffin control than deposit removal. It was suggested that changes should be made in the operating conditions which cause paraffin accumulation such as temperature change in the production tubing and flow lines, loss of light hydrocarbon compounds from the crude oil mixture, and prevention of precipitated paraffin crystals to agglomerate in the well producing fluid. A number of oil field operators were successful in removing the semi-fluid paraffin deposits from high capacity oil wells by periodically pumping the wells at higher flow rates. Ward[55] further mentioned that the above stated method could lead to formation damage due to gas or water coning. Several production methods were suggested to control paraffin build-up problems as follows:'"

- Maintaining a vacuum in the annulus of the well-bore to reduce heat loss from the produced formation fluid in the tubing. The presence of vacuum minimizes the heat loss by eliminating the medium required to transfer heat between the tubing and the surrounding formation.
- Minimizing heat loss from the produced formation fluid in the transportation lines with a use of small diameter flow-lines. Small diameter pipe reduces the travel time of flowing fluid that leads to lower heat loss to the surrounding through pipe walls.
- Using a backpressure regulator on the production tubing to prevent vaporization of light hydrocarbons from the produced oil.

Injection of heated gas was also reported in some gas lifted wells to prevent paraffin deposition. This method was limited to field application due to the low heat capacity of the injected gas.'

Removal of paraffin deposits had always been a never-ending problem for the oil operators. Oil industry was always in search of more economical method for paraffin removal. Plastic coated pipes served a two-fold purpose in wells with potential paraffin and corrosion problems by preventing paraffin build-up and protecting the tubing string or flow-line against the corrosive elements. White[69] stated that the success of plastic coating to prevent paraffin build-up was 80-85% dependent upon the coating application procedure and from 15-20% on the plastic coating material. According to Jordan,[70] surface roughness was the main factor contributing to the characteristics and amount of the paraffin deposition.

Even though the use of plastic coated tubing strings and flow-line was proved to be a successful means of preventing paraffin deposition, in some cases plastic coated equipment was not able to prevent paraffin build-up on the inner surfaces of the production and transportation lines. Jordan'" explained this phenomenon by analyzing the physical and chemical characteristics of three widely used oil field plastics that are given below:

- Phenol formaldehyde – It has excellent resistance to temperature, chemicals, and molecule infusion such as H_2O, H_2S, and CH,. It has a very glossy, smooth surface. In the case of contact with abrasive material such as sand, it deforms very badly and thus affects the surface smoothness.
- Epoxy Phenolic – This type of coating has less resistance to chemicals, temperature, and molecule infusion as compared to phenol formaldehyde. It has more erosion resistance to abrasive materials than phenol formaldehyde.
- Polyurethane – This type of plastic coating is the least resistant to temperature, chemicals, and small molecule infusion among all these mentioned plastic coating types. In the case of an abrasive environment, polyurethane has a tendency to deform slightly and maintain its smoothness.

By looking at the physical characteristics of all these plastic coating types, it was recommended to use phenol formaldehyde or epoxy phenolic in abrasion free producing wells. In case of abrasive environment, use of polyurethane was recommended to control paraffin build-up problems.

In 1978, a linear kinetic cell (LKC) was introduced to control scale formation in the water system.” In the early 1980s, the LKC system was tested on various types of oils in an attempt to find the applications of LKC system in oil industry. Tests of LKC system showed positive results in preventing paraffin accumulation by polarization and stabilization of molecules within the fluid.

Paraffin molecules are present in the crude oil in dipole stage. Due to the intimate contact with oil for several years, these paraffin molecules have positive and negative charge ends. The LKC system involves polarization of charged paraffin molecules to prevent deposition and thus molecular suspension within the flowing fluid. The LKC system had great advantages over the past methods of paraffin removal. Use of the LKC system for paraffin removal resulted in the elimination of chemical solvents, paraffin disposal problems, routine hot oiling operations to remove paraffin deposits, and increased production. As shown in Figure 4.11, untreated crude oil with paraffin molecules enters from one end of the LKC system and passes through the highly charged electric field.” Such high-energy electrical forces polarize the charged molecules in the oil and orient the positive and negative ends of the polarized molecules in such a way that the molecules come out from the LKC system in the form of a molecular chain. Once the molecular chain of the paraffin molecules is formed, the force of attraction between the tubing wall and paraffin molecules is weakened due to the unavailability of free positive and negative ends. Such phenomenon results in the suspension and stabilization of the paraffin molecules in the crude oil and prevents molecules to adhere on the tubing walls and flow-lines.

During late 1980s, a large number of wells with severe paraffin accumulation problems were treated by using biological products.[72,73] During experimental treatment operations, three biological products were tested in the field. Two of those three biological products were in a liquid form and contained anaerobic bacteria in the range of 10^6-10^9 bacteria cells/ml. In addition, the third biological product was in the powdered form and contained a mixture of aerobic bacteria with a cell concentration of 10^{12} cells/gm. A liquid biocatalyst and an inorganic nutrient were also included in the powdered biological product system to supplement the growth of aerobic bacteria and to enhance the metabolic (decomposition) reactions of high molecular weight paraffin into smaller molecules within the crude oil. These biological products, supplied by three different manufacturers, had non-toxic and non-hazardous properties.

Depending on the severity of paraffin accumulation, the frequency of treatment varied from one to two treatments per month. While using liquid biological product, one to six gallons of the liquid was used to pump down in between the tubing string and casing. The treatment was followed by brine water flush to allow the liquid biological product mixture to reach the paraffin-affected area in the well bore. When treating with the powdered product, a mixture of brine water and powdered product used to pump in the annular space between the tubing string and casing followed by a brine water flush. Before injection of the flush water, it was required to add specific amount of biocatalyst and inorganic nutrient in the flush water, which would supplement the bacterial growth in the injected biological product mixture and enhance metabolic reactions in paraffin deposits.

Because bacteria need water to live and metabolize available hydrocarbons through contact with oil/water interface, Bishop and Woodward[72] recommended selecting the wells for biological treatment that had water cut in excess of 1%. Reduction in bacterial activity was reported in low water cut wells. However, a combination of biological, mechanical, or thermal methods was also suggested for treating wells with a water cut less than 1%. In addition, a number of difficulties were encountered while treating flowing wells due to high flow rates, gas expansion, and lower water cut. One of the reasons for paraffin treatment failure using biological treatment methods was the high fluid level of produced formation fluid in the annulus. High fluid level in the annulus hindered the placement of biological products to the paraffin affected area in the well-bore. For high fluid level wells, circulation of biological mixture was recommended for proper placement of the treatment mixture to the production zone for paraffin deposit removal. The presence of hydrogen sulfide (H_2S) in the well can inhibit bacterial activity. According to Bishop and Woodward,[72] the biological treatment was failed in two wells with a H_2S concentration in excess of 6% in the solution gas. After 60 days of treatment operations, the concentration of H_2S reduced the bacterial count to 10^2 bacteria cell/ml that resulted in the failure of paraffin treatment operation. The biological treatment method was practiced on 563 wells in Central Texas and Alberta. The need for hot oiling as a combination method to control problems was completely eliminated in most of those wells.

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