REVIEW OF PARAFFIN CONTROL AND REMOVAL IN OIL WELLS USING SOUTHWESTERN PETROLEUM SHORT COURSE SEARCHABLE DATABASE

by

NOMAN SHAHREYAR, B.S.Ch.E.

A THESIS
IN
PETROLEUM ENGINEERING

Submitted to the Graduate Faculty of Texas Tech University in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE IN
PETROLEUM ENGINEERING

Approved

December, 2000
ACKNOWLEDGEMENTS

I am grateful to the Department of Petroleum Engineering at Texas Tech University for providing me with competitive departmental graduate scholarship and giving me the opportunity to reach this stage in my education and development as an aspiring engineer. I am also thankful to the Southwestern Petroleum Short Course (SWPSC) Association and Watford Professors for financially supporting me as a research assistant throughout my education at Texas Tech University.

To my thesis advisor, Dr. Lloyd Heinze, I would like to express my gratitude for all his valuable guidance. His assistance on the problems I faced to complete the thesis project was extremely helpful.

In addition, I am thankful to Dr. Scott Frailey and Dr. George Asquith for agreeing to be on my thesis committee and patiently answering all my questions. Their suggestions were very helpful as I worked through the revisions of my thesis.

I would also like to express my thanks to Dr. James Lea for providing me with the technical literature on the paraffin treatment methods. I am also grateful to Dr. Paulus Adisoemarta for his assistance and guidance in developing the SWPSC searchable database. I am thankful to Dr. Herald Winkler for volunteering the out-of-stock SWPSC conference proceedings from his personal collection, which were helpful to me as I needed them to make a complete set of the SWPSC volume to develop the SWPSC searchable database. I would also like to acknowledge Dr. Akanni Lawal’s assistance in my efforts to complete my duties as a graduate student advisor and in my attempts to
develop my technical writing skills. I am thankful to Ronda Brewer, Joan Blackmon, Jennifer Weitman, Joseph McInerney, Margaret Ceja, and my friends at the Texas Tech University for their co-operation.

Finally, I am grateful to my Dad, Masood Shahreyar, my Mom, Raees Fatima, and my brother, Rehan Shahreyar for encouraging me to attend Texas Tech University for my graduate education.
TABLE OF CONTENTS

ACKNOWLEDGEMENTS .................................................................................................................. ii
ABSTRACT ...................................................................................................................................... vi
LIST OF TABLES ............................................................................................................................... vii
LIST OF FIGURES ............................................................................................................................ viii

CHAPTER

1. INTRODUCTION ................................................................................................................................. 1
   1.1 Background Information .............................................................................................................. 1
   1.2 Scope of Work ............................................................................................................................. 3
   1.3 Objectives .................................................................................................................................... 4

2. LITERATURE REVIEW ...................................................................................................................... 6
   2.1 Chemistry of Petroleum Hydrocarbons ..................................................................................... 6
       2.1.1 Paraffin or Alkane Series ................................................................................................. 8
       2.1.2 Cycloparaffin or Naphthene Series ............................................................................... 10
       2.1.3 Aromatic or Benzene Series ......................................................................................... 10

   2.2 Basics of Paraffin Deposits ........................................................................................................ 13
       2.2.1 Causes of Paraffin Deposition ....................................................................................... 19

   2.2.2 Methods of Paraffin Prevention and Removal ................................................................. 21
       2.2.2.1 Mechanical Methods ............................................................................................... 22
       2.2.2.2 Thermal Methods .................................................................................................. 23
       2.2.2.3 Chemical Methods .................................................................................................. 23

   2.3 Adobe Systems Incorporated .................................................................................................... 28

   2.4 Society of Petroleum Engineers ............................................................................................... 30
ABSTRACT

The SWPSC Association, Inc. is a non-profit educational organization. The objective of the SWPSC is to disseminate technical knowledge about existing oil field problems, innovations/improvements in different areas of petroleum engineering, on-going research projects, and field-proven techniques to efficiently and economically solve various field problems. As of date, forty-six volumes of the SWPSC conference proceedings have been published over the past 46 years, comprising of 1641 conference proceedings. An initiative is undertaken to archive the SWPSC conference proceedings in the electronic format. A detailed methodology is outlined to archive the SWPSC conference proceedings from paper to the electronic format and to develop the SWPSC searchable database with the use of previously available computer software. The SWPSC database, developed in this work, is tested for its efficiency to retrieve the technical papers on paraffin control and removal methods that have been presented over the past 46 years of the SWPSC annual conferences. An overview of mechanical, thermal, chemical, and other published methods for paraffin treatment is provided after reviewing the 24 out of 36 retrieved SWSPC papers. In addition, the Society of Petroleum Engineers (SPE) image library is used to retrieve technical papers on paraffin treatment methods from the SPE collection of technical papers. After reviewing 19 out of 310 SPE technical papers, a summary of thermal, and chemical methods for paraffin control is outlined. The paper retrieval efficiency of both of these technical paper databases is compared and analyzed for retrieving papers related to paraffin control and removal methods.
LIST OF TABLES

4.1 A detailed summary of search results performed on the SWPSC searchable database with a keyword “Paraffin” ................................................. 67

4.2 A list of authors of the SWPSC technical papers on Paraffin Treatment Methods during the SWPSC annual conference (1954-1999) ....................... 72

5.1 A detailed summary of search results performed on the SPE image library with a keyword “Paraffin” ................................................................. 101

5.2 A list of authors of the SPE technical papers on Paraffin Treatment Methods, Presented during the SPE conference (1951-1997) ....................................... 106
LIST OF FIGURES

2.1 Structural formulas of some of the members of Paraffin or Alkane Series...........9
2.2 Structural formulas of some of the members of Cycloparaffin or Napthene Series.................................................................11
2.3 Structural formulas of some of the members of Aromatic or Benzene Series.......12
2.4 A 1995 survey of the different states in the United States with paraffin related problems........................................................................14
2.5 A molecular structure for Asphaltene......................................................16
2.6 Prediction of the amount of Asphaltene deposition from crude oil versus the volume of six different n-paraffin solvents.................................................18
2.7 An illustration showing the electric downhole heater.....................................24
2.8 An illustration showing hot oil injection......................................................25
2.9 Screen shot of the SPE image library’s paper search engine..........................32
3.1 An illustration of steps involved in developing the SWPSC searchable database...35
3.2 Adobe Capture 2.0 program’s main window..............................................41
3.3 Adobe Capture 2.0 program’s preferences window......................................42
3.4 Adobe Capture 2.0 program’s Input Folder Setup window..........................43
3.5 Adobe Capture 2.0 program’s Output Folder Setup window.......................44
3.6 Adobe Capture 2.0 program’s scan startup window....................................46
3.7 Adobe Acrobat 4.0 program’s Open window............................................48
3.8 Adobe Acrobat program’s General Info window showing document details of some enhanced SWPSC PDF document.................................49
3.9 Adobe Catalog 4.0 program’s New Index Definition window.......................51
3.10 Adobe Catalog program’s Options window ........................................... 52
3.11 Adobe Catalog 4.0 program’s main window ........................................... 54
3.12 Adobe Acrobat 4.0 program’s search preferences window ....................... 55
3.13 Adobe Acrobat program’s Add Index window ......................................... 57
3.14 Adobe Acrobat program’s built-in search engine window ......................... 58
4.1 Total Number of papers published each year during the SWPSC
Conferences from 1954-1977 ........................................................................ 61
4.2 Total Number of papers published each year during the SWPSC
Conferences from 1978-1999 ........................................................................ 62
4.3 Year-to-year (1954-1969) comparison of the total SWPSC technical
papers versus SWPSC papers retrieved by keyword search “Paraffin.” ........ 64
4.4 Year-to-year (1970-1985) comparison of the total SWPSC technical
papers versus SWPSC papers retrieved by keyword search “Paraffin.” ....... 65
4.5 Year-to-year (1986-1999) comparison of the total SWPSC technical
papers versus SWPSC papers retrieved by keyword search “Paraffin.” ....... 66
4.6 Year-to-year (1954-1969) comparison of the total SWPSC technical
papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin
Treatment Methods ....................................................................................... 69
4.7 Year-to-year (1970-1985) comparison of the total SWPSC technical
papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin
Treatment Methods ....................................................................................... 70
4.8 Year-to-year (1986-1999) comparison of the total SWPSC technical
papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin
Treatment Methods ....................................................................................... 71
4.9 Hollow Sucker Rod String .......................................................................... 76
4.10 Improvements in Oil Production during pre-squeeze, post-squeeze, and
after hot oiling is resumed ........................................................................... 82
4.11 Schematic diagram of Linear Kinetic Cell.................................88

4.12 Number of remedial hot oil treatments required on the wells in Central Texas and Canada with biological treatment program.........................91

4.13 Number of remedial hot oil treatments required on the wells in Central Texas and Canada with biological treatment program..............................92

4.14 Improvement in well production with the installation of magnetic fluid conditioner.................................................................94

5.1 Total Number of papers published each year during the SPE Conferences from 1951-1975...............................................................96

5.2 Total Number of papers published each year during the SPE Conferences from 1976-1997.................................................................97

5.3 Year-to-year (1951-1966) comparison of the total SPE technical papers and SPE papers retrieved by keyword search “Paraffin”.................................98

5.4 Year-to-year (1967-1981) comparison of the total SPE technical papers and SPE papers retrieved by keyword search “Paraffin”.................................99

5.5 Year-to-year (1982-1997) comparison of the total SPE technical papers and SPE papers retrieved by keyword search “Paraffin”.................................100

5.6 Year-to-year (1951-1966) comparison of the total SPE technical papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin treatment methods.........................................................103

5.7 Year-to-year (1967-1981) comparison of the total SPE technical papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin treatment methods.........................................................104

5.8 Year-to-year (1982-1997) comparison of the total SPE technical papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin treatment methods.........................................................105

5.9 Crude monthly rate production plot from well AG-50 against time........110
CHAPTER 1
INTRODUCTION

Today, almost every individual in the industry refers to publications/journals pertaining to their concerned field. Publications/journals, without any doubt, help individuals to gain knowledge from the past experiences and keep them updated with the up-coming technology. Publications also help individual to develop and master their professional skills. More can be learned about on-going research projects in the desired area of interest by referring to the publications. These publications can be published as a result of annual meetings, technical workshops, conferences, and seminars that are hosted by different professional/educational organizations. Some of the examples of such professional/educational organizations are: Society of Petroleum Engineers (SPE), American Institute of Chemical Engineers (AICHE), American Society of Mechanical Engineers (ASME), and Southwestern Petroleum Short Course (SWPSC). The Southwestern Petroleum Short Course Association, Inc. (SWPSC) aims to disseminate valuable knowledge and to update educators, researchers, and industry professionals by hosting an annual conference in Lubbock, Texas.

1.1 Background Information

The SWPSC Association, Inc. is a non-profit educational organization. The SWPSC headquarters is in the Department of Petroleum Engineering at Texas Tech
University, Lubbock, Texas. The Department of Petroleum Engineering at Texas Tech University annually hosts the SWPSC conference in Lubbock, Texas.

The objective of the SWPSC is to disseminate technical knowledge about existing oil field problems, innovations/improvements in different areas of petroleum engineering, on-going research projects, and field-proven techniques to efficiently and economically solve various field problems. Papers presented during the SWPSC conference are categorized into the following areas:

- Drilling and well completions,
- Artificial lift,
- Stimulation and workovers,
- Reservoir operations and enhanced oil recovery,
- Production Handling,
- Environmental control,
- General Interest.

These categories contain subject areas such as corrosion and paraffin control, sucker rod pumping, gas lifting, production optimization, enhanced oil recovery, well stimulation, and drilling operations. The SWPSC technical papers, resulting from the SWPSC conference, are presented by the scholars, researchers, and oil field personnel. The next subsection illustrates the work required to organize the proceeding papers resulting from the SWPSC conference.
1.2 Scope of Work

As of 2000, forty-six volumes of the SWPSC conference proceedings have been published over the past 46 years. The forty-six volumes of the SWPSC comprise of 1641 conference proceedings. The SWPSC conference proceedings are one of the assets for the Petroleum Industry. Oil and gas operators have presented a majority of the conference papers from the Permian Basin region. In addition, the SWPSC conference has also been successful in attracting presenters from all over the United States and different parts of the world. Therefore, these conference proceedings are a good knowledge base for petroleum engineering professionals, especially from the Permian Basin region, to gain knowledge and develop technical skills.

The Department of Petroleum Engineering is the place from where these published proceedings of the SWPSC are distributed to various libraries, oil companies, and individuals all over the world. Unfortunately, the SWPSC headquarters does not have a complete set of the 46 SWPSC volumes. It can be a time consuming and aggravating process to find some desired conference paper from a set of SWPSC proceeding volumes that are not present at one place.

In addition, one volume of the SWPSC, with an average of 325 pages, is added to the SWPSC storage closet every year. As the time passes by, the number of published proceedings will grow and storage of these catalogs might become a problematic issue. It is required to find a way to save and archive this historical set of knowledge base on the past experiences.
An initiative is undertaken to archive the SWPSC conference proceedings in an electronic format that will preserve the conference papers presented over the past 46 years. The SWPSC proceeding volumes, in the electronic format, will be easily accessible and eliminate the storage limitation issue. In addition, the SWPSC proceeding volumes will be facilitated with the efficient paper searching capabilities. This will save considerable paper-look-up time for finding any available particular information by eliminating the manual search process in the SWPSC paper volumes. The next section outlines the objectives of this work.

1.3 Objectives

The objectives of this thesis are as follows:

- to develop an electronic database of the SWPSC technical papers using commercially available software;
- to test the effectiveness of the SWPSC electronic database by retrieving the SWPSC conference papers on paraffin control and removal methods, published over the past 46 years;
- to summarize and categorize all the treatment methods for paraffin control and removal from the SWPSC electronic database;
- to retrieve and review the technical papers on paraffin control and removal methods using Society of Petroleum Engineers (SPE) papers database;
- to summarize and categorize the knowledge gained after reviewing the SPE technical papers on paraffin treatment methods;
to analyze and compare the paper retrieval effectiveness and depth of the technical information, provided by the retrieved papers from both of the electronic paper databases (SWPSC and SPE) in the area of paraffin control and removal methods.

The objectives of this thesis are accomplished in the next five chapters. The second chapter of this thesis provides a basic knowledge on the chemistry of petroleum hydrocarbons, composition of paraffin deposits, causes of paraffin deposition, and other treatment categories of paraffin prevention and removal. A brief overview of the computer software required for developing SWPSC searchable database, and the Society of Petroleum Engineers (SPE) is also outlined in the second chapter. The third chapter has a detailed methodology to develop SWPSC searchable database. After the SWPSC is developed, the SWPSC technical papers are retrieved on the paraffin control and removal methods tests its search efficiency. After reviewing these retrieved papers, all the paraffin treatment methods are summarized and categorized in the fourth chapter. In chapter five all of the SPE technical papers are summarized and categorized on the paraffin control and removal methods. The SPE database is used to retrieve the set of technical papers. At the end conclusions are drawn and recommendations are made in the sixth chapter.
CHAPTER 2
LITERATURE REVIEW

Paraffin control and removal has always been considered a severe problem in the oil fields since the beginning of the oil industry. Paraffin deposition can lead to loss in oil production and transportation problems by accumulating in the tubing, producing formation face, valves, and flow-lines. Various types of mechanical, thermal, and chemical based methods have been available to the oil producers to economically combat the formation and removal of paraffin deposits.

This chapter presents a basic knowledge on the chemistry of petroleum hydrocarbons, composition of paraffin, causes of paraffin deposition, and general methods that are available to control and remove paraffin deposition. A brief overview of the computer software is also given here to introduce the reader to the software that will be used to develop the SWPSC electronic database in this work. At the end of the chapter, an overview on the Society of Petroleum Engineers (SPE) organization and the SPE image library is presented.

2.1 Chemistry of Petroleum Hydrocarbons

Petroleum crude consists mainly of a mixture of carbon and hydrogen compounds that are called “Hydrocarbon Compounds.” Crude oil also contains small amount of compounds containing sulphur, nitrogen, and oxygen. A number of hydrocarbon series
have been identified in crude petroleum. General formulas for most of the commonly
found hydrocarbon series in the crude oil are given below:

- Paraffin or Alkane Series \((C_nH_{2n+2})\),
- Cycloparaffin or Naphthene Series \((C_nH_{2n})\),
- Aromatic or Benzene Series \((C_nH_{2n-6})\),

where \(n\) represents the number of each element in the hydrocarbon compound.

Petroleum hydrocarbons can be further categorized into saturated and unsaturated
hydrocarbons. A saturated hydrocarbon is a hydrocarbon compound in which all the carbon
atoms are attached to the hydrogen atoms rather than combining with themselves with one
or more double bonds.\(^1\)\(^\text{3}\) The saturated hydrocarbons have only single bonds in the
compounds. An unsaturated hydrocarbon is a hydrocarbon compound in which all the
carbon atoms are attached to the hydrogen atoms. In addition, unsaturated hydrocarbons
have one or more double bonds in the hydrocarbon compound.

Petroleum hydrocarbons that belong to the saturated hydrocarbon group are stable
compounds. For this reason, they are the least chemically reactive among the petroleum
hydrocarbon series. This is because of the absence of double bonds in the compound. In
contrast, the hydrocarbons that are classified as the unsaturated hydrocarbons are unstable
compounds due to the presence of double bond in the hydrocarbon compound. Unsaturated
hydrocarbons are reactive to chemicals and heat. In addition, the reactivity of unsaturated
hydrocarbons increases with the increasing molecular weight of the compound.
Furthermore, the stability of chemical structuring or bonding of the carbon and hydrogen
atoms in the different series of petroleum hydrocarbon compounds is important factor

7
because it decides the placement of the first or simplest member in each series of the petroleum hydrocarbon series.

2.1.1 Paraffin or Alkane Series

Hydrocarbon compounds that belong to the paraffin or alkane series can be derived from a general molecular formula: $C_nH_{2n+2}$. Alkanes are also called saturated hydrocarbons with a name of each member ending with "-ane" such as: methane, ethane, propane, and hexane. Figure 2.1 shows the structural formula of some of the members that belong to paraffin series. Methane, $\text{CH}_4$, is the simplest hydrocarbon that belongs to the paraffin series. Paraffin hydrocarbons are the least reactive in nature among the different series of hydrocarbons. Starting from butane (Figure 2.1), it can be seen that there are two possible arrangements of carbon and hydrogen atoms in butane compound. Hydrocarbon compounds that have the same molecular formula but various structural arrangements are called isomers. For example, the carbon atoms of butane can be arranged either in a straight chain or in a branched chain and each carbon atom is linked as a single bond to other carbon atoms in the hydrocarbon compound. In straight chain arrangement, each carbon atom is attached to one or a maximum of two other carbon atoms, but in branched chain arrangement at least one of the carbon atoms in the hydrocarbon compound is attached to three other carbon atoms. As the number of carbon atoms in the hydrocarbon compounds increases, the possible number of isomers also increases rapidly.
Figure 2.1. Structural formulas of some of the members of the Paraffin or Alkane Series. 
2.1.2 Cycloparaffin or Naphthene Series

Cycloparaffins or napthenes can be represented by the same chemical formula as olefins, i.e. \( C_nH_{2n} \). Napthenes are saturated closed chain hydrocarbon compounds in which each carbon atom is attached to two other carbon atoms. The existence of the cyclopropane and cyclobutane hydrocarbons is not possible because of the instability of chemical structuring or bonding in each of these members of cycloparaffin. The simplest naphthene compound contains five carbon atoms attached with a single bond to each other. Figure 2.2 shows the structural formulas of some of the members of the cycloparaffin hydrocarbon series.

2.1.3 Aromatic or Benzene Series

The aromatic or benzene series hydrocarbons are closed chain hydrocarbon compound and can be derived from the general molecular formula \( C_nH_{2n-6} \). The chemical name of every aromatic hydrocarbon ends with “-ene” such as: benzene, toluene, xylene, and naphthalene. Benzene is the simplest hydrocarbon compound from the aromatic hydrocarbons series. A benzene ring contains six carbon atoms that are linked with a double bond to one of their neighbor carbon atoms. Aromatic hydrocarbons can contain single or multiple benzene rings in their structural formula. Figure 2.3 illustrates some of the members that belong to the aromatic hydrocarbon series.
Figure 2.2. Structural formulas of some of the members of Cycloparaffin or Naphthene Series."
Figure 2.3. Structural formulas of some of the members of Aromatic or Benzene Series.
2.2 Basics of Paraffin Deposits

Paraffin is a waxy, solid substance that naturally occurs in crude oil. Paraffin can cause production and transportation problems by accumulation in the well tubing, well-bore perforations, pore spaces of producing formation, flow-lines, and the surface equipment. Figure 2.4 shows a 1995 survey of various oil producing states in the United States that had paraffin build-up problems\textsuperscript{12} (cited by Fan and Llava\textsuperscript{41}).

Paraffin deposits can range from pure white paraffin wax to the deposits that totally consist of asphaltenes. Paraffin wax molecules are classified as a group of straight or branched chain alkanes that can range from \( C_{18}H_{38} \) to \( C_{38}H_{78} \) with very little branching, depending on the hydrocarbon composition of the crude oil. Paraffin wax tends to precipitate out from the crude oil in the oil production operations due to reduction in temperature and pressure in the well-bore and the transportation lines. “Precipitation” is the process in which the low-molecular-weight paraffin wax molecules become insoluble in the crude oil at a specific temperature and pressure and come out from the crude oil in the form of paraffin wax crystals.\textsuperscript{6} The low-molecular-weight molecules of paraffin wax precipitate out of the crude oil and act as nucleation agents for the high-molecular-weight paraffin molecules. These nucleation agents either adhere to the tubing wall and flow-lines or remain in the crude oil in the form of dispersed paraffin wax crystals. As the temperature and pressure decreases, additional high-molecular-weight paraffin wax molecules precipitate out of the crude oil and start collecting and forming a layer on the previously precipitated paraffin molecules, adhered to the tubing walls, flow-lines, and present in the crude oil. Such phenomenon of paraffin collection on the precipitated
Figure 2.4. A 1995 survey of the different states in the United States with paraffin related problems.\textsuperscript{41,42}
paraffin hydrocarbons is called “Deposition.” Paraffin wax is chemically non-reactive by nature and insoluble in the crude oil at producing conditions. The molecular weight of the paraffin compounds can range from 250 to about 550. In addition, paraffin deposits may possibly contain aromatic hydrocarbons, napthanes, resins, asphaltenes, oil, water, sand, and silt.

Asphaltenes are dark-colored condensed aromatic hydrocarbons (Figure 2.5) that can possibly contain nitrogen, oxygen, sulphur, and different metals in the molecule. Asphaltenes are relatively high molecular weight compounds with the molecular weight ranging from 1,000 to about 140,000. Resins are high-molecular-weight hydrocarbons similar in composition to asphaltenes. These organic compounds are insoluble in acids and bases.

Asphaltene deposition is not as much dependent on the change in temperature and pressure as compared to paraffin wax deposition. Asphaltene deposition is mainly caused by the chemical changes in the crude oil. Asphaltene are present in the crude oil in dispersed/ floating condition. Resins surround the asphaltene particles and help to keep asphaltenes in the dispersed form in the crude oil. Introduction of fluids such as CO₂, HCl, pentane, hexane, and gasoline can strip away the outer part (resins) of the asphaltene particles, present in the crude oil. Such phenomenon causes the asphaltenes to precipitate out of the crude oil.

A number of quick tests can differentiate paraffin wax from the asphaltenes. Paraffin is soluble in warm gasoline whereas asphaltenes are insoluble in warm gasoline. Paraffin wax melts in the temperature range of 104-248 °F whereas asphaltenes do not melt.
Figure 2.5. A molecular structure for Asphaltene.$^{18}$
but it decomposes at temperature above 300 °F. Aromatic solvents such as benzene, toluene, xylene, chloroform, carbon tetrachloride, and carbon disulfide have the ability to dissolve asphaltenes and resins. In addition, the asphaltenes and resins are insoluble in propane, butane, and refined petroleum products such as kerosene and diesel oil. Figure 2.6 illustrates a relationship between the amount of asphaltene deposition by addition of paraffin solvents, ranging from C₅H₁₂ to C₁₀H₂₂, in the crude oil.

According to Newberry, "These deposits are very difficult to remove from a system because normal thermal methods of hot oil or water are totally ineffective. Removal is limited to tedious mechanical cutting operations or solvent soak techniques. The use of readily available cheaper solvents such as diesels, kerosene or condensates are also ineffective because their surface tension are too low for effective solution of the asphaltenes" (p. 4).

Paraffin wax can be further categorized into macro-crystalline and microcrystalline paraffin waxes. Macro-crystalline wax is a mixture of straight chain saturated hydrocarbons with 20 to 50 carbon atoms. Macro-crystalline wax forms large needle-shape crystals during the deposition process. On the other hand, microcrystalline wax mainly consists of complex branched chain and cyclic compounds having 30 to 60 carbon atoms. Microcrystalline wax produces smaller crystals upon deposition as compared to macro-crystalline wax.

Solubility of paraffin in crude oil or pure petroleum solvents decreases with the increase in molecular weight of the paraffin molecule. Paraffin waxes are soluble in solvents such as pentane and gasoline. These waxes are insoluble in aromatic solvents such
Figure 2.6. Prediction of the amount of asphaltene deposition from crude oil versus the volume of six different n-paraffin solvents.\textsuperscript{23}
as benzene and toluene. Generally, the composition of paraffin deposits, after removing suspended material such as sand and silt, contains:

- 40-60% paraffin wax,
- 30% crude oil,
- 10% resins, and asphaltenes.

2.2.1 Causes of Paraffin Deposition

Deposition of paraffin in the production and transportation equipment is mainly caused by the loss of solubility of wax in the crude oil. Reduction in either temperature or pressure or both contributes to the precipitation of paraffin from the crude oil. Reduction in temperature and pressure causes loss of light hydrocarbons from the crude oil solution that decreases the ability of the oil to hold the paraffin molecules in the crude oil and causes precipitation of paraffin from the produced oil.

According to Singhal et al., “When the equilibrium between the crude oil and its paraffin molecules is disturbed, paraffin precipitation takes place. The disturbance of equilibrium occurs due to reduction in temperature and/or pressure of the flowing stream” (p. 251).

Precipitation of paraffin can occur at any point from the bottom-hole of the well-bore to the storage tanks. “Cloud” point and pour point are the two common measurements of the paraffin characteristics. Cloud point is the temperature at which paraffin first begins to precipitate out of the crude oil solution. As the temperature decreases, these
precipitated paraffin particles attract to each other and form an interlocking paraffin-particle-network. At one point, the crude oil become so thick that it does not pour. The temperature at which the crude oil does not pour is called the "Pour" point. Precipitation of paraffin begins at the cloud point temperature and pressure of the dissolved paraffin content in the crude oil.

Reduction in temperature, either in the well-bore or the surface flow-line, is caused by the expansion of gases, heat loss to the casing and cement in the well-bore, heat loss to well-bore surrounding formation area, and heat loss to the surroundings of the transportation lines (air, and soil). During the deposition process, paraffin precipitates out of the crude oil as single crystals. Such single crystals remain in the crude oil solution in dispersed form and tend to agglomerate around a nucleus, namely asphaltenes, to form relatively larger paraffin particles. Paraffin accumulation is caused due to three deposition mechanisms: 7, 8, 15, 25, 27-29

- Molecular diffusion,
- Shear dispersion,
- Brownian motion.

Molecular diffusion occurs when the temperature of the flowing fluid in the tubing and flow-lines falls below the cloud point temperature and paraffin molecules are transported towards the walls of tubing and flow-lines due to the concentration gradient. In shear dispersion, each paraffin molecule interacts with the nearby paraffin molecules, in slower or faster moving streamlines, due to the rotary motion in the flowing fluid. Such multiple collision leads to the dispersion of the paraffin particles in the flowing fluid.
Molecular diffusion is driven by the concentration gradient whereas shear dispersion is driven by the velocity gradient. In Brownian motion, thermally agitated oil molecules continually bombard small and solid paraffin wax particles. Such phenomenon leads to a small random Brownian movement of the bombarded paraffin particles. According to Burger et al., "Molecular diffusion dominates at the higher temperatures and heat flux conditions, whereas shear dispersion is dominant mechanism at the lower temperatures and low heat fluxes" (p. 26).

2.2.2 Methods of Paraffin Prevention and Removal

Prevention of paraffin deposits can be achieved by keeping the paraffin wax dissolved in the produced oil or by minimizing the adhesion or aggregation process of wax particles on the equipment surfaces. According to Matlach and Newberry, "If the wax content of the crude oil is low to moderate (0-10%) these problems are periodic and handled on an 'as needed' basis. With wax contents above 10% those crude experience severe deposition and flow problems necessitating constant treatment to ensure continued production" (p. 321). Various methods are available to handle paraffin deposition. In general, these methods can be categorized into three main categories: "

- Mechanical.
- Thermal,
- Chemical.

21
2.2.2.1 Mechanical Methods

There are several mechanical methods to remove paraffin from the production tubing and flow-lines. Rod scrapers, wire-line scrapers, flow-line scrapers, soluble and insoluble plugs are the most commonly used mechanical tools for cleaning paraffin deposits.\(^9,19,31,32\)

A rod scraper is a cutting device that is attached to the sucker rod string in the rod pump wells. Rods scrapers cut the accumulated paraffin from the inside wall of the production tubing due to the reciprocating action of the rods. The scraped paraffin wax falls in the produced formation fluid in the tubing and carries up to the surface with the produced fluid.

According to Allen and Roberts,\(^9\) a wire-line scraper is another type of paraffin cutting tool that is widely used for paraffin deposit removal in the flowing or gas lift wells. In wire-line scraper, a scraper is attached to the wire-line tool. The wire-line units can be operated and controlled manually or automatically by some timing device.

Soluble and insoluble plugs are mainly used to remove paraffin deposits from the flow-line. Soluble plugs are solid, short cylinders that are made of microcrystalline wax or naphthalene. On the other hand, insoluble plugs are usually hard rubber or sharp-edged plastic spheres. One of the advantages of soluble plugs is their tendency to dissolve in the crude oil after the paraffin treatment operation. Therefore, the need to recover these paraffin-cutting plugs is eliminated. Injecting soluble or insoluble plugs from one end of the flow-line and then applying fluid pressure behind the plugs to push them along the flow-lines accomplish removal of paraffin deposits.
2.2.2.2 Thermal Methods

Paraffin treatment using thermal methods involves adding external heat to the system by minimizing heat loss to the surroundings. Installation of down-hole electric heaters for heating crude oil near the producing formation (Figure 2.7) comes into the thermal treatment category, but this method is limited due to high treatment expenses and electrical power availability. In the crude transportation lines, heat loss from the produced formation fluid can be minimized by proper insulation of flow-lines or maintaining high pressure in the flow-lines to prevent light hydrocarbons from coming out of the produced formation fluid.

As documented, the circulation of hot oil or hot water in the well-bore is one of the most popular thermal methods for paraffin removal. Hot oil or hot water is injected down the casing and up the tubing to melt or increase the solubility of the paraffin deposits in the produced oil, accumulated on the tubing wall and the producing formation face (Figure 2.8). Use of steam has also been reported in some areas to melt paraffin or asphaltenes in the tubing, casing, or flow-lines. However, after application of thermal methods it is necessary to maintain the temperature of the crude oil above the cloud point temperature of the paraffin content in order to prevent the further deposition.

2.2.2.3 Chemical Methods

Chemicals are used to control paraffin deposition by dissolving the accumulated paraffin, inhibiting the paraffin wax crystal growth, and inhibiting the adherence of paraffin
Figure 2.7. An illustration showing the electric down-hole heater.
Figure 2.8. An illustration showing hot oil injection.\textsuperscript{33}
wax crystals to the tubing wall and flow-lines. Chemical treatment of producing wells with paraffin problems involves use of four categories of chemicals: 7, 19, 31, 39, 40

- Solvents,
- Dispersants,
- Detergents,
- Wax crystal modifiers.

Solvents used for dissolving existing paraffin deposits generally contain high aromatic content. Solvents such as produced condensate, casing head gasoline, kerosene, diesel oil, butane, pentane, xylene, toluene, benzene, carbon tetrachloride, and carbon disulfide are used for remedial treatment of the paraffin deposits. Kerosene, diesel oil, and low aromatic content condensates do not dissolve asphaltenes. However, condensates with high aromatic contents, xylene, and toluene are excellent solvents for asphaltenes. The solvent treatment technique involves penetration of the solvent into the paraffin deposits to re-dissolve them into the crude oil.

Dispersants are chemical compounds that have the ability to keep paraffin particles in the dispersed form as they crystallize in the produced crude oil. Dispersants neutralize the attractive forces between paraffin crystals itself and the attractive forces between the paraffin crystals and tubing walls, transportation lines, and surface equipment. Such phenomenon prevents the paraffin crystals from uniting and forming layers on the pipe surfaces. 7, 31, 39, 40 Paraffin treatment, using dispersants involves pumping the mixture of dispersant and water/chemical solvent into the annulus of the well-bore. The dispersant mixture is pumped out with the produced formation fluid.
Detergents are surface-active compounds that have a tendency to water-wet the paraffin crystals, formation, production tubing, and the flow-lines in the presence of water. Such wetting action neutralizes the cohesive forces among the crystals and attractive force between paraffin crystals, tubing, and flow-lines. Detergents help in breaking up the paraffin deposits and preventing the dispersed paraffin particles to accumulate along the tubing or flow-lines.

Crystal modifiers are usually polymeric materials such as polyethylene or any branched chain polymers that inhibit or alter the wax crystal growth to prevent paraffin crystal growth. These crystal modifiers combine with the paraffin molecules and alter the paraffin crystal growth. According to Woo et al., "Crystal modifier are usually polymeric materials which prevent paraffin deposition by disrupting nucleation, co-crystallization or modifying the crystal. They may also adsorb on the paraffin crystal preventing agglomeration or deposition" (p. 2).

According to Holloway, "It is now recognized that the application of chemical surfactants or detergents is extremely paraffin removal, and that the use of chemical dispersants and crystal modifiers are effective in preventing its deposition" (p. 3). In addition, Newberry and Barker recommended using paraffin dispersants and detergents prior to well stimulation such as acidizing or fracturing for paraffin deposit removal in the well-bore.
2.3 Adobe Systems Incorporated

With the advancement in computer and information technology, the demand for available literature/information in the electronic document format is increasing everyday to cut down the consumption of paper material. As compared to paper documents, there are several advantages of using documents in the electronic format:

- Fast and easy distribution,
- Compact storage,
- Efficient search capability.

Adobe Systems, Inc. is one of the computer software companies involved in the development of software tools to convert information from paper to the electronic format. Adobe Systems, Inc. was founded in 1982 and is one of the software companies in the United States. The company's headquarters is based in San Jose, California.

Reams of paper documents can be converted into searchable portable document format (PDF) files with the use of Adobe's Acrobat Capture 2.0 software. According to Tredennick, "PDF supports keyword searches within the documents or across an entire library. We can locate trial materials in seconds, browse the results, and print what we need. Previously, support staff spent days sifting through rooms full of papers to accomplish this" (p. 1).

Using Adobe Capture 2.0, paper documents can be scanned as a bitmap page images followed by conversion into PDF documents. Such electronic PDF files have exactly the same page layout, text format, and graphics as the original paper pages. In
addition, these PDF files are fully searchable for any particular word or a string of words inside the PDF document or a set of PDF documents.

Acrobat Capture works with four built-in optical character recognition (OCR) systems. While processing text information from the paper image file, each of the OCR systems agrees upon the validity of each word or letter by comparing with the words in the dictionary and then returns the information to the Capture program. Based on the combined information from each of the OCR engines, Acrobat Capture finally generates characters to store them into the created PDF file of that particular paper image document.

Acrobat Catalog 4.0 builds a full-text index file by copying the words from the collection of PDF documents and then storing them into the index file. In addition, the Catalog program saves the document details into the same index file by extracting them from the document information section of each of the PDF document, provided that document details were manually edited into the PDF document or a set of documents by using Adobe Acrobat 4.0 (Education Version) program.

PDF documents provide an opportunity to the user to manually edit the document details such as paper title, subject, author's name, and document related keywords into the document information section of the PDF file. The document information section is initially empty after documents are scanned and processed by the Capture 2.0 program. Adobe Acrobat 4.0 (Education Version) can be purchased to edit the document details in the document information section of the PDF files. Adobe Acrobat 4.0 is facilitated with the built-in paper search capabilities to find the search the contents of the PDF document(s).
Adobe Acrobat Reader can be used by the users for viewing the PDF document. The disadvantage of using Acrobat Reader is that it cannot search the contents that are present in the PDF document or a collection of PDF documents. Acrobat Reader + Search is a modified version of the Acrobat Reader, developed by Adobe Systems, that can be used to search for any particular information from a collection of PDF documents, based on user provided keyword or a string of keywords. Acrobat Reader's search engines access an index file of the PDF document(s), created by the Adobe Catalog 4.0 software, to match the text in the PDF files with the word or phrase provided by the user. Both, Acrobat Reader and Acrobat Reader + Search, are freely distributed software and can be obtained from the Adobe Systems website.

2.4 Society of Petroleum Engineers

The Society of Petroleum Engineers (SPE) Inc. is the largest individual petroleum membership organization based in Richardson, Texas. The primary objective of the SPE organization is to gather and serve professional engineers, scientists, and managers in the exploration and production of oil and exchange the emerging technology to meet the world's energy needs all over the world. Currently, SPE membership list has more than 50,000 registered professionals from different oil and gas producing countries. Presently, there are 145 SPE sections in 54 countries.

There are more than 30,000 technical papers in the SPE library's electronic database that have been published during past years of SPE conferences. These papers are available both on the SPE image library CD-ROM and on the SPE website.
The SPE image library can be searched for any particular content in the collection of SPE papers by using Wordkeeper retrieval software, developed by Columbus Digital Connections. The SPE image library consists of two parts:

- a master disc,
- a set of image discs.

The SPE master disc contains, in the text format, the first page of each of the SPE papers submitted since 1951. In addition, the first-page text documents do not contain figures, footnotes, Greek symbols, and equations. Each of this first page text document is linked with the corresponding complete paper including figures and equations, saved as a paper’s photographic image on the SPE image discs.

Wordkeeper retrieval software (Figure 2.9) can be run from the master disc to perform searches on the first page content of all the SPE papers. A search can be performed on a collection of SPE papers by providing a parameter or a combination of parameters such as SPE paper number, author, and keywords. Based on the provided search parameter(s), a list of SPE paper titles is displayed on the screen. Each displayed title is electronically linked with the corresponding paper’s first page text document and the paper’s full photographic image for viewing the abstract or full contents of the original document.

The SPE image library uses structured and unstructured searching strategies for finding a list of SPE papers. In structured searches, the user given search parameter(s) are matched with contents of the document information fields of all the SPE papers. Such searchable document information fields include: SPE paper number, title, author(s).
Figure 2.9. Screen shot of the SPE image library’s paper search engine.
publication date, author’s organization (company, and university), conference name or location, and journal’s name (journal of petroleum technology). Unstructured searches rely on matching the user provided word or a phrase with the contents of the first page of each of the SPE papers, present in the text document format.
CHAPTER 3

METHODOLOGY

The purpose for developing the SWPSC searchable database is to provide the petroleum industry with a tool that would help them quickly retrieve any available information, contained in the SWPSC proceedings in the electronic format. This chapter describes the detailed methodology to develop the SWPSC searchable database. Forty-six years of the SPWSC conference proceedings, in the paper format, are archived into the electronic format.

With the use of previously available software, the electronic version of the SWPSC proceedings will be fully searchable for the contents that are contained in the collection of SWPSC documents. In addition, the storage limitation issue to store the SWPSC paper volumes will be eliminated. The following sequence (Figure 3.1) is used to develop the SWPSC searchable database:

1. Install the computer software required to develop the searchable electronic database for the past 46 years of SWPSC conference proceedings.
2. Scan and convert the paper copies of SWPSC conference proceedings to PDF files using Adobe Capture 2.0 software.
3. Condition the previously converted raw PDF files. Adobe Acrobat 4.0 software is used to edit and manually feed the document details of all the conference papers into the document information section of the corresponding PDF documents. Data
Installation of the computer software (Adobe Capture 2.0 & Adobe Acrobat 4.0) → Scanning and conversion of the SWPSC paper documents into PDF documents (raw) using Adobe Capture 2.0 → Conditioning of the SWPSC PDF files (raw to enhanced format) using Adobe Acrobat 4.0 → Indexing of the enhanced SWPSC PDF files using Adobe Catalog 4.0 → Customization of the Adobe Acrobat 4.0 program → SWPSC searchable database

Figure 3.1. An illustration of steps involved in developing the SWPSC searchable database.
entry includes the following: conference paper title, subject, author's name, and technical keywords related to the corresponding conference paper.

4. Index the conditioned PDF electronic files, using Adobe Catalog 4.0 software, by creating an index file. This index file is used by the Acrobat Reader's built-in search engine to find the desired conference papers from the SWPSC electronic database.

5. Customize the Acrobat Reader 4.0 software to perform an electronic search/query on the collection of conditioned or enhanced SWPSC conference PDF files.

The next five sections give a detailed description of the procedure involved in developing SWPSC searchable database.

3.1 Installation of Computer Software

It is required to install the computer software for later use to develop the SWPSC searchable database. List of the necessary computer software is given below:

- Acrobat Capture 2.0,
- Adobe Acrobat 4.0 (Education Version).

Given below is the step-by-step procedure to install the above-mentioned software. Because the computer being used to develop searchable database has Windows NT 4.0 installed on it as an operating system, all of the software installation procedure is given for Windows NT 4.0.
3.1.1 Installation of Adobe Capture 2.0

To install the Adobe Capture 2.0 software, the following sequence is followed:

1. Restart and log on to the computer with administrative privileges. An account
   with administrative privileges is required to install software on the computer.

2. On the backside of the computer processor box, locate any available parallel port
   and plug the hardware key, provided with the Acrobat Capture 2.0, into the parallel
   port. The hardware key is required to be plugged in into the parallel port in order to
   process the documents in Acrobat Capture 2.0. This hardware key is designed to
   scan and process a maximum of 20,000 pages. If more than 20,000 pages are
   required to be processed, an additional hardware key is required to continue the
   processing job.

3. Place the compact disc containing Acrobat Capture 2.0 software into the CD-ROM
   drive. A new window appears on the monitor screen showing different file folders
   available on the Capture 2.0 software compact disc.

4. Run the Acrobat Capture installation program by clicking on setup icon, located
   under the Capture2 file folder on the inserted compact disc.

5. The Acrobat Capture installation wizard window appears on the screen. Follow the

6. Read the software license agreement and then click the Accept button to proceed to
   the next screen.

7. A component selection window appears on the screen, showing the program files
   available for installation. Select all the programs and proceed to the next screen.
8. A new window appears with a list of available drivers for the scanning device. Select the driver that matches with your scanning device and then proceed to the next screen by clicking the OK button.

9. In the next window, enter your name, your organization and the serial number for the Capture software. After completing the user information form, click the Next button to start the software installation.

10. A message window appears after the software installation is complete.

11. Fill out and submit the software registration form and then restart the computer.

12. Installation of Acrobat Capture 2.0 software is done. Acrobat Capture program is now ready to scan paper documents and convert them to the desired file format.

3.1.2 Installation of Adobe Acrobat Reader 4.0 (Education Version)

Acrobat Reader 4.0 can be installed by following the steps below:

1. Restart Windows NT 4.0 and log on to the computer with administrator privileges.

2. Insert the Adobe Acrobat 4.0 (Education Version) compact disc in the CD-ROM. An Adobe welcome window appears on the screen.

3. Click the next button located on the welcome window.

4. Click the “Install Adobe Acrobat 4.0” button. Follow the step-by-step instructions on the screen provided by the Acrobat installation wizard.

5. Read the software license agreement and then click the Accept button to proceed to the next screen.

6. Check the custom button and then click the next button.
7. Select all the program files and then click on the next button to proceed to the user information window.

8. Fill out your name, your organization (optional), and the serial number for your Adobe Acrobat 4.0 software. Click on the next button to the start software installation.

9. After completion of software installation, a registration window appears on the screen.

10. Fill out and submit the software registration form and then restart the computer.

11. Once the registration is complete, a message window appears on the screen asking to restart the computer in order to complete the software installation.

3.2 Scanning and Conversion of SWPSC Conference Proceedings

After the installation of required computer software, the paper copies of all the conference papers are to be scanned that have been published during the last 46 years. Therefore, all the SWPSC conference proceeding catalogs are gathered and separated into single pages starting from the 1954 conference year catalog.

Hewlett Packard’s Scan Jet II scanner, equipped with an automatic document feeder (ADF), is selected to scan the conference paper documents. Because approximately 14,580 conference proceeding pages were scanned and converted to image files, the ADF scanner is the best selection to scan a stack of conference pages at a time rather than scanning each single page manually.
Prior to starting the paper-scanning job, it is required to customize the program settings for the Acrobat Capture 2.0 program before performing a paper-scanning job. A step-by-step procedure to setup the Capture 2.0 program is given below:

1. Run the Acrobat Capture 2.0 program.
2. Click the File tab on the menu bar, as shown in Figure 3.2.
3. Select the Preferences option on the pull-down bar. A Capture-Preferences window appears on the screen.
4. Select the options, as shown in Figure 3.3, and then click the OK button.
5. Click the Input tab on the menu bar followed by Add Input Folder, located on the Input tab’s pull-down bar. An Input Folder Setup window appears on the screen.
6. Fill out the Description and Location text fields, as illustrated in the Figure 3.4, and then click the OK button.
7. Click the Output tab on the menu bar followed by Setup Output Folder. An Output Folder Setup window appears on the screen.
8. Select the setup options in the Output Folder window, as shown in Figure 3.5, and then click the OK button.

Customization of the Acrobat Capture 2.0 program is complete. The scanning procedure using Capture 2.0 program followed by format conversion of the scanned copies is outlined. The following sequence of steps accomplishes the scanning of the SWPSC conference papers followed by format conversion of the scanned papers:

1. Start the Acrobat Capture 2.0 program.
Figure 3.2. Adobe Capture 2.0 program's main window.
Figure 3.3. Adobe Capture 2.0 program’s preferences window.
Figure 3.4. Adobe Capture 2.0 program's Input Folder Setup window.
Figure 3.5. Adobe Capture 2.0 program’s Output Folder Setup window.
2. Place a set of complete conference paper on the scanner’s ADF with the paper title facing in the opposite direction to the scanner’s ADF surface.

3. Click the Process tab on the menu bar followed by the Scan to Input Folder tab. A scan window appears on the screen.

4. Fill out the Document Name text field. As shown in Figure 3.6, it is recommended to use document names such as 1954001, 1984043, where the first four digits stand for the year when the paper was published and the last three digits are used to differentiate each paper as they are numbered in the conferences’ paper catalogs.

5. Click the Start button on the Scan window to start the scanning of the conference paper.

6. Once the scanning job is done for any particular set of a conference paper, click the Process tab followed by the Process Input folder tab. This starts the format conversion of the scanned paper from image to the portable document format (pdf).

7. Repeat the steps 2-6 to scan and convert the whole collection of SWPSC conference papers into the PDF format.

3.3 Conditioning of SWPSC PDF Files

It was required to read all of the SWPSC conference proceedings and make a list of keywords for each of those read papers to condition the SWPSC PDF documents. The main objective for finding technical keywords from each of the conference papers, presented during 46 years of the SWPSC conference, was to use them as an input parameter in the document information section of each of the conference paper’s PDF files.
Figure 3.6. Adobe Capture 2.0 program’s scan startup window.
In addition, other parameters were also entered in the document information section of each paper such as: paper title, subject, and author's name. For demonstration purpose, a step-by-step procedure is outlined below on how to condition the SWPSC conference papers:

1. Start the Abode Acrobat Reader 4.0 program.

2. Click the File tab on the menu bar. A pull-down bar appears on the screen.

3. Click the Open tab, located on the pull-down bar.

4. An open window appears asking to locate the SWPSC PDF files on the computer.

5. Locate the file folder containing SWPSC files by pressing the arrow button as shown in Figure 3.7.

6. Double click on any of the SWPSC conference paper's PDF file to display the paper.

7. Click the File tab on the menu bar.

8. Move the mouse pointer to the Document Info tab, listed on the pull-down bar.


10. Fill out all of the empty fields in the general info box by entering the title, subject, author's name, and technical keywords from the displayed conference paper. As an example, completed Document Information of one of the SWPSC PDF documents as shown in Figure 3.8.

11. Click the OK button to close the General Info window.

12. Click the File tab and then click the Save tab, located on the pull-down bar, to save the conditioned or enhanced conference paper PDF document.
Figure 3.7. Adobe Acrobat 4.0 program’s Open window.
Figure 3.8. Adobe Acrobat program’s General Info window showing document details of some enhanced SWPSC PDF document.
13. Repeat the steps 2-12 to scan and convert the whole collection of SWPSC conference papers.

3.4 Indexing of enhanced SWPSC PDF Files

Adobe Acrobat Catalog software builds a single full-text index file of all the PDF document files. A searchable database of all the text present in a PDF document or a collection of documents is called a “full-text” index. Adobe Acrobat Reader uses a full-text index file to locate any desired PDF document from the collection of indexed PDF documents. The steps below create the full-text index file for the collection of 46 years of SWPSC enhanced PDF documents:

1. Run the Adobe Acrobat Catalog 4.0 program.
2. Click the Index tab on the menu bar.
3. Click the New tab on the pull-down bar. As shown in Figure 3.9, a New Index Definition window appears on the screen.
4. Fill out the Index Title field with an appropriate title for the index file.
5. Click the Options button. An Options window appears on the screen. Select the appropriate option boxes, as shown in Figure 3.10, and click the OK button.
6. Click the Add button located to the right of the Include Directories text field area on the New Index Definition window. A new Browse for Folder window appears requesting location of the file folder that contains conditioned or enhanced PDF files of all the SWPSC conference papers.
Figure 3.9. Adobe Catalog 4.0 program’s New Index Definition window.
Figure 3.10. Adobe Catalog program's Options window.
7. Locate the file folder that contains SWPSC conditioned PDF files and then click the OK button.

8. Click the Build button to start creating an index file. A new window appears on the screen asking to specify the file directory or location to save the index file. Save the index file in the same folder where the SWPSC enhanced PDF files are saved and then press the OK button to start the indexing process. Figure 3.11 shows the indexing of enhanced PDF files in progress.

3.5 Customization of Adobe Acrobat 4.0 program

In this section, a step-by-step procedure is presented on how to customize the search parameter fields in the Acrobat search engine. In addition, a procedure is also outlined on how to link the SWPSC index file with the Acrobat search engine for finding information from a collection of SWPSC conference papers.

1. Start the Acrobat Reader 4.0 program.

2. Click the File tab on the menu bar.

3. Move the mouse pointer to the Preferences tab on the pull-down bar and click the Search tab. An Acrobat Search Preferences window appears on the screen.

4. Select the options, as shown in Figure 3.12, and click the OK button.

5. Click the Edit tab on the menu bar and move the mouse pointer to the Search tab. A new pull-down bar appears.

6. Click the Select Indexes tab. An Index Selection window appears.
Figure 3.11. Adobe Catalog 4.0 program’s main window.
Figure 3.12. Adobe Acrobat 4.0 program’s search preferences window.
7. Click the Add button and locate the index file, as shown in Figure 3.13. Select the index file and click the Open button.

8. Click the Ok button on Index Selection window.

The customization of the Acrobat Reader is done. A search can be performed from any available information in the developed SWPSC searchable database. The given sequence below is followed to find desired technical information from the SWPSC searchable database:

1. Run the Acrobat Reader 4.0 program.

2. Click the Edit tab on the menu bar.

3. Move the mouse pointer to the Search tab and click the Query tab. An Adobe Acrobat Search Engine appears on the screen, as shown in Figure 3.14.

4. Complete the desired text field(s) in the search engine window and click on the Search button. Based on the entered information, a list of found SWPSC technical paper(s) is displayed on the screen.

After the SWPSC database is developed, the whole database is copied to compact disc (CD). Only 3 CDs are required to accommodate this whole collection of SWPSC PDF documents.

Searches can be performed on the SWPSC papers’ database by paper title, subject, author’s name, keyword(s), or any combination of all these search parameters. This searchable database supports both structured and unstructured searching methods. Unlike the unstructured search routine in SPE image library where only the contents on the first
Figure 3.13. Adobe Acrobat program’s Add Index window.
Figure 3.14. Adobe Acrobat program’s built-in search engine window.
page of the conference paper can be searched, the SWPSC database permits to search for any particular information from the full content of the SWPSC PDF file or set of PDF files.
The SWPSC searchable database, developed in this work, is a fast and efficient knowledge base tool for the petroleum industry especially from the Permian Basin. Available literature can be quickly found on the possible solutions to a particular existing problem. By using the SWPSC searchable database, it is now possible to perform searches for any particular information that is available in a collection of the SWPSC PDF documents.

The SWPSC searchable database supports both the structured and unstructured search strategies. Unlike the unstructured search procedure in the SPE image library where only the word or a phrase, present on the first page of the collection of SPE technical papers, can be matched with the user provided search parameter (word or phrase), the SWPSC searchable database allows searches from the full contents of the SWPSC PDF documents. The SWPSC searchable database is used in the next section to test its efficiency for retrieving SWPSC technical papers that have been published on paraffin control and removal methods over the past 46 years of the SWPSC annual conference.

4.1 Test of the SWPSC Searchable Database

By using the Adobe Reader (Adobe Reader with built-in search engine) software, a search is performed to retrieve the SWPSC conference papers. There are 1641 SWPSC conference papers that have been published over the past 46 years (Figures 4.1 and 4.2).
Figure 4.1. Total Number of Papers published each year during the SWPSC Conferences from 1954-1977.
Figure 4.2. Total Number of papers published each year during the SWPSC Conferences from 1978-1999.
The word “paraffin” is used one-by-one in the title and keyword text-field sections of the Adobe Reader’s built-in search engine. The search results, by using keyword text-field, are illustrated in Figures 4.3, 4.4 and 4.5. Thirty-six out of 1641 SWPSC conference papers are retrieved that contain literature related to paraffin. Table 4.1 provides detailed search results of the retrieved papers.

4.2 Review and Summary of Paraffin Treatment Methods

The SWPSC searchable database is fast and precise tool for retrieving the SWPSC conference papers on paraffin treatment methods. The maximum number of papers, retrieved after the paper search from the SWPSC searchable database, are found by performing a search using a word “Paraffin” in the keyword text-field section of the Adobe Reader search engine (Table 4.1). These 36 SWPSC papers are reviewed to find all the treatment methods for paraffin control and removal. After reviewing all these 36 papers, it is found out that 24 out of 36 contain literature on paraffin treatment methods (Figures 4.6, 4.7, and 4.8). In Table 4.2, a list of authors is tabulated who have presented technical papers on paraffin control and removal methods over the past 46 years of the SWPSC annual conference. All the published treatment methods for paraffin control and removal are categorized and summarized in the next four subsections.
Figure 4.3. Year-to-year (1954-1969) comparison of the total SWPSC technical papers versus SWPSC papers retrieved by keyword search "Paraffin."
Figure 4.4. Year-to-year (1970-1985) comparison of the total SWPSC technical papers versus SWPSC papers retrieved by keyword search "Paraffin."
Figure 4.5. Year-to-year (1986-1999) comparison of the total SWPSC technical papers versus SWPSC papers retrieved by keyword search "Paraffin."
Table 4.1. A detailed summary of search results performed on the SWPSC searchable database with a keyword "Paraffin."

<table>
<thead>
<tr>
<th>Year</th>
<th>Total # of Papers</th>
<th>Papers retrieved with a word &quot;Paraffin&quot;</th>
<th>Papers containing Paraffin Treatment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Search by Title text-field</td>
<td>Search by Keyword text-field</td>
</tr>
<tr>
<td>1954</td>
<td>21</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1955</td>
<td>31</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1956</td>
<td>46</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1957</td>
<td>44</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1958</td>
<td>44</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>1959</td>
<td>48</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1960</td>
<td>43</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1961</td>
<td>39</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1962</td>
<td>45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1963</td>
<td>34</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1964</td>
<td>29</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1965</td>
<td>32</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1966</td>
<td>28</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1967</td>
<td>26</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1968</td>
<td>26</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1969</td>
<td>26</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>1970</td>
<td>24</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1971</td>
<td>29</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1972</td>
<td>25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1973</td>
<td>31</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1974</td>
<td>27</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1975</td>
<td>44</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1976</td>
<td>47</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1977</td>
<td>36</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1978</td>
<td>33</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 4.1. (Continued)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total # of Papers</th>
<th>Papers retrieved with a word “Paraffin”</th>
<th>Papers containing Paraffin Treatment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Search by Title text-field</td>
<td>Search by Keyword text-field</td>
</tr>
<tr>
<td>1979</td>
<td>28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1980</td>
<td>32</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1981</td>
<td>40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1982</td>
<td>26</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1983</td>
<td>38</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1984</td>
<td>43</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1985</td>
<td>43</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1986</td>
<td>37</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1987</td>
<td>28</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1988</td>
<td>40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1989</td>
<td>39</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1990</td>
<td>46</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1991</td>
<td>37</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1992</td>
<td>40</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1993</td>
<td>41</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>1994</td>
<td>31</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1995</td>
<td>41</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1996</td>
<td>37</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>1997</td>
<td>41</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1998</td>
<td>35</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1999</td>
<td>41</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
Figure 4.6. Year-to-year (1954-1969) comparison of the total SWPSC technical papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin Treatment Methods.
Figure 4.7. Year-to-year (1970-1985) comparison of the total SWPSC technical papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin Treatment Methods.
Figure 4.8. Year-to-year (1986-1999) comparison of the total SWPSC technical papers, papers retrieved by keyword "Paraffin," and papers on Paraffin Treatment Methods.
Table 4.2. A list of authors of the SWPSC technical papers on Paraffin Treatment Methods during the SWPSC annual conference (1954-1999).

<table>
<thead>
<tr>
<th>Author</th>
<th># of papers on Paraffin Treatment Methods</th>
<th>Category and Method for Paraffin Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addison G. E.</td>
<td>1</td>
<td>Thermal (Hot Oiling)</td>
</tr>
<tr>
<td>Brown M. J.</td>
<td>1</td>
<td>Thermal (Exothermic Reaction)</td>
</tr>
<tr>
<td>Bishop M. D.</td>
<td>2</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Brock R.</td>
<td>1</td>
<td>Chemical (Squeeze Treatment with Dispersant)</td>
</tr>
<tr>
<td>Barker K. M.</td>
<td>2</td>
<td>Thermal (Hot Oiling)</td>
</tr>
<tr>
<td>Cushner M. C.</td>
<td>1</td>
<td>Chemical (Crystal Growth Modifier)</td>
</tr>
<tr>
<td>Cotney C. R.</td>
<td>1</td>
<td>Chemical (Solvent)</td>
</tr>
<tr>
<td>Corney J. D.</td>
<td>1</td>
<td>Other (Magnetic Fluid Conditioning)</td>
</tr>
<tr>
<td>Chee W.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Cunningham J. A.</td>
<td>1</td>
<td>Thermal (Hot Oiling)</td>
</tr>
<tr>
<td>Crawford J. D.</td>
<td>1</td>
<td>Chemical (Solvent)</td>
</tr>
<tr>
<td>Dobbs J. B.</td>
<td>1</td>
<td>Thermal (Exothermic Reaction)</td>
</tr>
<tr>
<td>Garbis J. S.</td>
<td>1</td>
<td>Chemical (Crystal Wax Modifier)</td>
</tr>
<tr>
<td>Haynes J.</td>
<td>1</td>
<td>Other (Linear Kinetic Cell)</td>
</tr>
<tr>
<td>Herman J.</td>
<td>1</td>
<td>Thermal (Hot Oiling)</td>
</tr>
<tr>
<td>Ivanhoe K.</td>
<td>1</td>
<td>Thermal (Hot Oiling), Other (Plastic Coating)</td>
</tr>
<tr>
<td>Jordan R. M.</td>
<td>1</td>
<td>Other (Plastic Coating)</td>
</tr>
<tr>
<td>King S. R.</td>
<td>1</td>
<td>Chemical (Solvent)</td>
</tr>
<tr>
<td>Author</td>
<td># of papers on Paraffin Treatment Methods</td>
<td>Category and Method for Paraffin Treatment</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>King S. R.</td>
<td>1</td>
<td>Chemical (Solvent)</td>
</tr>
<tr>
<td>Kostoff N. V.</td>
<td>1</td>
<td>Chemical (Dispersant)</td>
</tr>
<tr>
<td>Lukehart C. O</td>
<td>1</td>
<td>Other (Butane Injection)</td>
</tr>
<tr>
<td>McKinney T. B.</td>
<td>2</td>
<td>Chemical (Solvent)</td>
</tr>
<tr>
<td>Mancillas G.</td>
<td>1</td>
<td>General</td>
</tr>
<tr>
<td>MsCaskill B. M.</td>
<td>1</td>
<td>Chemical (Solvent, Dispersant)</td>
</tr>
<tr>
<td>Mansure A. J.</td>
<td>1</td>
<td>Thermal (Hot Oiling)</td>
</tr>
<tr>
<td>Mendell J. L.</td>
<td>1</td>
<td>Chemical (Solvent, Dispersant, Crystal Wax Modifier)</td>
</tr>
<tr>
<td>Olsen H. R.</td>
<td>1</td>
<td>Chemical (Crystal Wax Modifier)</td>
</tr>
<tr>
<td>O’Grady C.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Snedeker K. D.</td>
<td>1</td>
<td>Mechanical (Scraper, Soluble Plug)</td>
</tr>
<tr>
<td>Shroyer L. L.</td>
<td>1</td>
<td>Other (Linear Kinetic Cell)</td>
</tr>
<tr>
<td>Trainer J. C.</td>
<td>1</td>
<td>General</td>
</tr>
<tr>
<td>Woo G. T.</td>
<td>1</td>
<td>Chemical (Crystal Wax Modifier)</td>
</tr>
<tr>
<td>Wilson J. J.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Woodward D. R.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>White J. M.</td>
<td>1</td>
<td>Other (Plastic Coating)</td>
</tr>
<tr>
<td>Ward J. L.</td>
<td>1</td>
<td>Mechanical (General)</td>
</tr>
<tr>
<td>Young M. A.</td>
<td>1</td>
<td>Mechanical (Rod Scraper)</td>
</tr>
</tbody>
</table>
4.2.1 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.\textsuperscript{55} 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.\textsuperscript{55} 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.\textsuperscript{55,56} 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 paraffin accumulation from the inside walls of the tubing string and flow-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\textsuperscript{55} 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\textsuperscript{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,\textsuperscript{57} 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 (Figure 4.9), heat loss to the well-bore surrounding formation was considerably reduced.\textsuperscript{55,75} 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\textsuperscript{55} recommended using hollow rod string in high paraffin producing fields because of high installation costs as compared to conventional rod installations.

4.2.2 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...
Figure 4.9. Hollow Sucker Rod String.\textsuperscript{75}
immediate paraffin treatment results. According to Snedeker,\textsuperscript{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.\textsuperscript{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, paraffin 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 paraffin 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. 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 Dobbs12 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.
4.2.3 Chemical Treatment Methods

Before the second half of the 20th century, most of the paraffin removal jobs were accomplished by mechanical means only. 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 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.\textsuperscript{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,\textsuperscript{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. Figure 4.10 shows the improvement in well production in one of the treated wells, from Test Lease No. 3, during pre-squeeze, post squeeze, and after hot oiling was resumed.\textsuperscript{60}
Figure 4.10. Improvements in Oil production during pre-squeeze, post-squeeze, and after hot oiling is resumed.

(12 – 0 pre-squeeze, 0 – 12 post-squeeze, 0 – 9 hot oiling)
According to Lukehart, 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, paraffin 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. 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. 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, "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).

4.2.4 Other Treatment Methods

A number of production techniques were practiced in the oil fields to prevent paraffin precipitation. According to Ward, 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 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 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, 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 H₂O, H₂S, and CH₄. 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.
Figure 4.11. Schematic diagram of Linear Kinetic Cell.\textsuperscript{71}
During late 1980s, a large number of wells with severe paraffin accumulation problems were treated by using biological products. 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 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 (H2S) in the well can inhibit bacterial activity. According to Bishop and Woodward, the biological treatment was failed in two wells with a H2S concentration in excess of 6% in the solution gas. After 60 days of treatment operations, the concentration of H2S 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. Figures 4.12 and 4.13 show the number of remedial hot oil treatments, required after the wells were put on the biological treatment program for paraffin deposit removal.
Figure 4.12. Number of remedial hot oil treatments required on the wells in Central Texas and Canada with biological treatment program.
Figure 4.13. Number of remedial hot oil treatments required on the wells in Central Texas and Canada with biological treatment program.
Some oil producers used magnetic fluid conditioners (MFC) to treat paraffin accumulation problems in the oil well.\textsuperscript{74} No external power was required to operate this magnetic tool. The MFC system made a great contribution in reducing paraffin treatment costs and increasing oil production. In the MFC system, produced crude oil and water is passed through strong permanent magnetic field within the tool. Strong magnetic fields inhibit the accumulation of scale and paraffin by changing the growth pattern of paraffin and scale crystals.

Installation of the MFC system required the rods and pump to be pulled up to the surface so that magnetic tool could be attached to the bottom of the pump. It was necessary to determine the environment in the well for effective MFC design. MFC installations were cost effective and environmentally safe as compared to chemical, thermal, or mechanical methods. Figure 4.14 illustrates the increase in well production after MFC was installed to control the severe paraffin accumulation problems in a particular well in Manistee County, Michigan.\textsuperscript{74} Prior to MFC installation, hot oiling, and chemical treatment methods were used to control paraffin build-up problems.
Figure 4.14. Improvement in well production with the installation of magnetic fluid conditioner.74

[Before Mag-well MFC (graph on the front side) – 0-55, After Mag-well MFC (graph on the backside) – 0-55]
CHAPTER 5
REVIEW OF SPE PAPERS ON PARAFFIN CONTROL
AND REMOVAL METHODS

The SPE image library contains 29,918 technical papers that have been presented in the SPE conference from 1951-1997. Figures 5.1 and 5.2 show the year-to-year distribution of these published SPE papers. By using the Wordkeeper retrieval software, a built-in software facilitated with the SPE image library, a search was performed to retrieve the SPE papers, containing literature on paraffin. The word “Paraffin” is used one-by-one in the title and keyword text-field sections of the Wordkeeper retrieval software. The search results are illustrated in Figures 5.3, 5.4, and 5.5. In addition, Table 5.1 provides detailed search results of the retrieved papers.

5.1 Review and Summary of Paraffin Treatment Methods

Paper search on the SPE image library, performed with a word “Paraffin” in the keyword text-field, resulted with 310 papers out of 29,918 SPE technical papers (Table 5.1). These 314 SPE papers are reviewed to find all the treatment methods for paraffin control and removal. After reviewing these papers it was found that only 19 out of 314 papers contained literature on paraffin treatment methods (Figures 5.6, 5.7, and 5.8). In Table 5.2, a list of authors is tabulated who have presented technical papers on paraffin control and removal methods. All the reviewed treatment methods for paraffin control and removal are categorized and summarized in the next subsections.
Figure 5.1. Total Number of papers published each year during the SPE Conferences from 1951-1975.
Figure 5.2. Total Number of papers published each year during the SPE Conferences from 1976-1997.
Figure 5.3. Year-to-year (1951-1966) comparison of the total SPE technical papers and SPE papers retrieved by keyword search "Paraffin."
Figure 5.4. Year-to-year (1967-1981) comparison of the total SPE technical papers and SPE papers retrieved by keyword search “Paraffin.”
Figure 5.5. Year-to-year (1982-1997) comparison of the total SPE technical papers and SPE papers retrieved by keyword search "Paraffin."
Table 5.1. A detailed summary of search results performed on the SPE image library with a keyword “Paraffin.”

<table>
<thead>
<tr>
<th>Year</th>
<th>Total # of Papers</th>
<th>Papers retrieved with a word “Paraffin”</th>
<th>Papers containing Paraffin Treatment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Search by Title text-field</td>
<td>Search by keyword text-field</td>
</tr>
<tr>
<td>1951</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1952</td>
<td>34</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1953</td>
<td>35</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>1954</td>
<td>39</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1955</td>
<td>73</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1956</td>
<td>76</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1957</td>
<td>86</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>1958</td>
<td>177</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1959</td>
<td>210</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>1960</td>
<td>189</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1961</td>
<td>226</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>1962</td>
<td>252</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>1963</td>
<td>231</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>1964</td>
<td>242</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1965</td>
<td>251</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1966</td>
<td>251</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>1967</td>
<td>263</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1968</td>
<td>291</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>1969</td>
<td>317</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1970</td>
<td>348</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1971</td>
<td>407</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1972</td>
<td>454</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>1973</td>
<td>393</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 5.1. (Continued)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total # of Papers</th>
<th>Papers retrieved with a word &quot;Paraffin&quot;</th>
<th>Papers containing Paraffin Treatment Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Search by Title text-field</td>
<td>Search by keyword text-field</td>
</tr>
<tr>
<td>1974</td>
<td>465</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1975</td>
<td>426</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1976</td>
<td>471</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1977</td>
<td>494</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>1978</td>
<td>471</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>1979</td>
<td>526</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1980</td>
<td>472</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>1981</td>
<td>584</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>1982</td>
<td>807</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>1983</td>
<td>813</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>1984</td>
<td>733</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>1985</td>
<td>859</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>1986</td>
<td>998</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>1987</td>
<td>990</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>1988</td>
<td>1251</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>1989</td>
<td>1220</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>1990</td>
<td>1290</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>1991</td>
<td>1940</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>1992</td>
<td>1579</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>1993</td>
<td>1736</td>
<td>3</td>
<td>14</td>
</tr>
<tr>
<td>1994</td>
<td>1801</td>
<td>6</td>
<td>16</td>
</tr>
<tr>
<td>1995</td>
<td>1598</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>1996</td>
<td>1933</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>1997</td>
<td>1612</td>
<td>7</td>
<td>25</td>
</tr>
</tbody>
</table>
Figure 5.6. Year-to-year (1951-1966) comparison of the total SPE technical papers, papers retrieved by keyword “Paraffin," and papers on Paraffin treatment methods.
Figure 5.7. Year-to-year (1967-1981) comparison of the total SPE technical papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin treatment methods.
Figure 5.8. Year-to-year (1982-1997) comparison of the total SPE technical papers, papers retrieved by keyword “Paraffin,” and papers on Paraffin treatment methods.
Table 5.2. A list of authors of the SPE technical papers on Paraffin Treatment Methods, presented during the SPE conference (1951-1997).

<table>
<thead>
<tr>
<th>Author</th>
<th>Number of Papers Presented on Paraffin Treatment Methods</th>
<th>Category and Method for Paraffin Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashton J. P.</td>
<td>1</td>
<td>Thermal</td>
</tr>
<tr>
<td>Beyer A. H</td>
<td>1</td>
<td>Other (Down-hole Emulsification)</td>
</tr>
<tr>
<td>Brown F. G.</td>
<td>2</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Barker K. M.</td>
<td>2</td>
<td>Thermal (Hot Oiling)</td>
</tr>
<tr>
<td>Cheyne A. J.</td>
<td>1</td>
<td>Other (Vacuum Insulated Tubing)</td>
</tr>
<tr>
<td>Collesi J. B.</td>
<td>2</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Credeur D. J.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Dobrota S. C.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Donovan S. C.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>George R. E.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Haynes H. H.</td>
<td>1</td>
<td>Chemical (Squeeze Treatment)</td>
</tr>
<tr>
<td>Khalil C. N.</td>
<td>2</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Kirspel L. J.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Lenderman G. L.</td>
<td>1</td>
<td>Chemical (Squeeze Treatment)</td>
</tr>
<tr>
<td>Lazar I. I.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Lukehart C. O.</td>
<td>1</td>
<td>Other (Butane Injection)</td>
</tr>
<tr>
<td>McSpadden H. W.</td>
<td>3</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Mitchell T. I</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Mansure A. J.</td>
<td>1</td>
<td>Thermal (Hot Oiling)</td>
</tr>
<tr>
<td>Nguyen H. T.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Osborn D. E.</td>
<td>1</td>
<td>Other (Down-hole Emulsification)</td>
</tr>
<tr>
<td>Purdy I. L.</td>
<td>1</td>
<td>Other (Vacuum Insulated Tubing)</td>
</tr>
<tr>
<td>Pelger J. W.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Romeu R. K.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Rabinovitz ??</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Rocha N. O.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Sutton G. D.</td>
<td>1</td>
<td>Other (Aqueous Solution System)</td>
</tr>
<tr>
<td>Santos P. C.</td>
<td>1</td>
<td>Chemical (Solvent)</td>
</tr>
<tr>
<td>Stefanesu M. M.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Santamaria S. S.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Scott T. A.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Silva E. B.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Streeb L. P.</td>
<td>1</td>
<td>Other (Biological Treatment)</td>
</tr>
<tr>
<td>Tyler M. L.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
<tr>
<td>Velasco T. T.</td>
<td>1</td>
<td>Thermal (Heat &amp; N₂ System)</td>
</tr>
</tbody>
</table>
5.2 Thermal Treatment Methods

Development of a thermal treatment process by generating in-situ heat and nitrogen offered an alternative method to hot oil and hot water treatments. The heat and nitrogen generating method required mixing of an aqueous solution of sodium nitrate (NaNO₃) with an aqueous solution of ammonium chloride (NH₄Cl). Mixing of these two aqueous solutions was performed on the surface. Chemical reaction between these two solutions produces nitrogen gas, heat, and non-damaging by-products (water, and sodium chloride).

Even though the chemical reaction between the two aqueous solutions started at the surface, the rate of reaction was controlled by adding a calculated amount of methanol/ acetic acid solution and manipulating pump rates to attain maximum generated heat at the predetermined depth in the well. Heat loss was also minimized by controlling the rate of chemical reaction that was one of the main disadvantages in the hot oil or hot water treatments. The heat and nitrogen generating system was designed to reach the maximum temperature of 462 °F.

McSpadden et al. stated that the paraffin treatment by heat and nitrogen generating system was long lasting than treatment by hot oil or chemical solvents in the treated wells. Even though it was possible to inject the aqueous mixture either in the tubing or the casing, the injection of the mixture was preferred through the tubing to predict the heat loss and maximum generated heat more accurately. In addition, it was recommended to pump the mixture in the annulus to avoid sucker rod pulling. Treatment procedure using heat and nitrogen generating system is as follows:
• Injection of xylene as a preflush in the amount of 50 gallons per foot of the depth interval.
• Injection of NaNO₃ and NH₄Cl as an aqueous mixture in the tubing.
• Shut-in of the well for 24 hours transfer the heat by conduction to the paraffin affected areas near the producing formation face.

According to Kirspel et al., the treatment using heat and nitrogen generating system was applied on well B during September 1985. Four treatments were performed on this well (Figure 5.9) in a time span of 10 months. Collesi et al. stated that after successful treatment of paraffin affected wells using heat and nitrogen generating system, the application of this method was extended to treat the flow-lines. The treatment mixture contained 50% aqueous solution of NaNO₃ and NH₄Cl, 43% xylene, 5% was dispersant, and 2% emulsifier. The well that was connected to the flow-line was shut-in and the treatment solution was pumped through the flow-line to remove paraffin, located in the Main Pass field area. The function of the emulsifier was to create an emulsion of the aqueous solution (NaNO₃ and NH₄Cl) and the chemical solvent (xylene) that would increase the paraffin dissolving capabilities of the chemical solvent due to generated heat in the system.

5.3 Chemical Treatment Methods

According to Santos, the solvent treatment was applied on one of the paraffin-affected wells (AG-50) in Renconcavo Bainano Basin, Northeastern Brazil. A monthly production of the crude oil from this well (AG-50) before treatment, after the first
treatment, and after the second treatment is illustrated in Figure 5.9. This well was treated twice using chemical solvent method with a four-month time interval. On the first job, the well was shut-in for four days after naptha was injected as a chemical solvent into the annulus. After the first treatment job, a slug of diesel oil was injected into the annulus and then well was shut-in for ten days to soak the well-bore nearby formation with injected diesel oil. Santos\textsuperscript{38} stated that the soaking time of solvents in chemical treatment jobs was an important factor to dissolve and remove paraffin deposits.

In 1985, a new squeeze treatment method was tested on two oil-producing wells in West Texas. According to Hayne and Lenderman,\textsuperscript{83} “The aim was to put a slow-dissolving solid paraffin inhibitor into the formation. The paraffin inhibitor was squeezed into the formation in liquid form and then caused to precipitate by an activator” (p. 552). Prior to the squeeze treatment, these two wells were being treated by hot oiling 3-4 times every year. A step-by-step procedure was followed to perform squeeze treatment in one of the wells in West Texas and is as follow:

- Injection and circulation of hot oil with one drum of paraffin dispersant down the annulus and up the tubing to pre-flush the well-bore before the squeeze treatment.
- Injection of 10 barrels of crude oil down the annulus, mixed with six drums of activator.
- Injection of 10 barrels of water into the annulus to separate the activator from the inhibitor.
Figure 5.9. Crude monthly rate production plot from well AG-50 against time.³⁸

(Pre-treatment = -48 to 0 months, after first treatment = 0 to 4 months,
after second treatment = 4 to 24 months)
• Injection of a mixture containing six drums of paraffin inhibitor with 60 barrels of crude oil down the annulus.

• Over-flush of 270 barrels of water into the annulus to push the previously injected fluids into the formation.

• Shut-in the well for 24 hours.

According to King and Cotney, "Unique condensate feedstocks can be blended and refined to produce formation and reservoir fluid compatible natural solvents" (p. 120). The natural solvents were also used in combination with the hot oil at a ratio of 10% by volume to the hot oil treatments. Such combination allowed the hot oil to dissolve low molecular weight paraffin and solvents to dissolve the high-molecular-weight paraffin particles. When using condensates for paraffin treatment, Cotney recommended injecting natural solvents in the ratio of 5-10% to the total volume in front of the condensate treatment.

5.4 Other Treatment Methods

Biological treatment using microorganisms (bacteria) was also one of the methods to control paraffin accumulation problems. These microorganisms were neutrally charged naturally occurring marine organisms that required water to survive and metabolize available hydrocarbons through contact with oil/water interface. In addition, these microorganisms required the biocatalyst and inorganic nutrient to supplement the bacterial growth and enhance the metabolic reactions in paraffin deposits. In 1991, the biological treatment was applied on 91 wells with paraffin accumulation problems in...
Oklahoma. One of the wells was located in Canadian County, Oklahoma. This well was previously being treated with paraffin solvent and paraffin dispersant to control the paraffin deposition. In addition, the well was also being hot oiled four times per year. Pelger recommended using the biological treatment method on this well. The well was batch treated with the biological products and then shut-in for 24 hours. The average oil production was increased by 36.5 barrels of oil per month. The average increase in production of oil from those 91 wells was 2664 barrels of oil per month. The biological treatment method reduced the paraffin treatment costs by 18.1% by eliminating chemical treatments, reducing hot oiling treatments cycles, and reducing mechanical cutting frequency of paraffin from the wells in that area.

Another attempt was made on the five wells with paraffin deposition problems in the Austin Chalk Formation in East Texas. Previously, these wells were being treated by hot oiling as often as twice a week. Each of these wells was batch treated by mixing one pound of paraffin treating bacteria and 12 gallons of biocatalyst with one barrel of water, injecting the mixture in the annulus, and flushing the well with 3 barrels of water. The wells were then shut-in for 24 hours to allow the biological product to react with the paraffin deposits in the well-bore. The frequency of biological treatment on these 5 wells ranged from 1 to 2 treatments per month. Santamaria and George concluded that the biological treatment was limited to wells that produced water and that had bottom-hole temperature below 210 °F.

In 1990, the vacuum insulated tubing was installed in one of the wells in the Norman wells oilfield, located in Northwest Canada. This oilfield had 167 producing...
wells of which 52 wells were rod-pumping wells and rests of them were gas lift wells.

Vacuum insulated tubing was comprised of two tubings with different diameters, welded at both ends of the tubing joints. The annular section of these welded tubings was evacuated to vacuum. The purpose of creating a vacuum in the tubing annulus was to minimize the heat loss to the area, surrounded by the tubing (casing, cement, and formation).

Prior to the vacuum insulated tubing installation, the paraffin was being removed by using the wire-line dewaxing/scraping tools. The frequency of paraffin treatment was once after every 3 days. After the installation of vacuum insulated tubing, the treatment frequency using wire-line scraping tools was reduced to once per month.

Down-hole emulsification of the produced formation fluid was also one of the methods to reduce paraffin deposition by forming an oil-in-water emulsion from the produced fluid in the well-bore and water wetting the steel surfaces with a water film to inhibit the adherence of paraffin wax on the tubing wall. Application of this method was dependent on the water cut and gas-oil ratio (GOR) of the producing well. This method required the water cut to be above 35% in the producing well to provide sufficient water for forming an oil-water emulsion and protective water film. In addition, the producing GOR below 1000 standard cubic ft. of gas per 1 barrel of oil was required to suppress the gas turbulence in the tubing. Gases with high flow rates would prevent the formation of an oil-water emulsion and water film. Below given sequence of steps was followed to treat each of those 6 wells using down-hole emulsification method:

- Injection of 300 barrels of hot oil down the annulus and up the tubing to clean the existing wax deposits from the well bore.
- Injection of a 100 barrel mixture of 0.2% (by volume) detergent with hot water (225 °F) into the annulus to coat the steel surfaces in the well-bore.
- Injection of 2% (by volume) aqueous solution down the annulus continuously for 7 weeks.

During the seven weeks of treatment period, no hot oiling was required in 4 out of 6 treated wells. On an average, the monthly hot oiling need to treat these 6 wells was reduced by 44%.

In 1974, an aqueous based chemical mixture was used for paraffin treatment in one of the wells, located in Trenton Formation. Prior to the water based chemical treatment, this well was being hot oiled on monthly basis for paraffin deposit removal. After the chemical treatment, the oil production was increased by almost 25%. In addition, the well was maintained its increased production for six months and no hot oiling was required during that time on this well. The aqueous based chemical treatment required the injection of 20 barrels of warm water with 20 gallons of chemical A into the well-bore. The chemical mixture was injected down the annulus and pumped back to the surface through the tubing. The chemical treatment was applied once every two weeks on this well.
CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

The SWPSC searchable database provides easy and fast searching/retrieving facilities to retrieve technical papers by searching paper title, subject, author, and keywords, presented over the past 46 years of SWPSC annual conference. A full-text search can be performed on the knowledgebase, available in the SWPSC database, by using Adobe Reader software. In addition, some of the advantages of SWPSC PDF documents include fast and easy electronic distribution and compact storage.

The paper retrieval capability of the SWPSC searchable database is more precise than the SPE image library for retrieving technical papers on the paraffin control and removal methods. A search on the SWPSC database, with a keyword “Paraffin”, retrieved 36 technical papers that have been published over the past 46 years. After reviewing these 36 papers, twenty-four papers were found to have treatment methods for paraffin control and removal. In contrast, a search with a same word (Paraffin) on the SPE image library resulted with 310 technical papers. After a review of those 310 SPE technical papers, it was found out that 19 papers had literature on the paraffin treatment methods. Chapters 4 and 5 of this thesis provide a summary of all the methods on paraffin control and removal that have been published in the SWPSC and SPE publications over the past five decades. It can be concluded that the SWPSC literature is more field-oriented whereas the SPE literature is more theoretical and research-oriented in the area of paraffin control and removal methods.
The knowledgebase, contained in the SWPSC and SPE databases, on paraffin control and removal methods is not evenly distributed by the paper authors. There are 34 authors in the SWPSC publications and 35 authors in the SPE technical papers, respectively, who have presented different methods for paraffin treatment over the past five decades. Names of only three authors (Mansure A. J., Barker K. M., and Lukehart C. O) were found to be in common in both the SPE and SWPSC databases.

A majority of papers that have been published in the SWPSC publications are related to chemical methods for paraffin treatment. On the other hand, the authors in the SPE papers are more inclined to talk about thermal (Heat and Nitrogen generating system) and biological ways of curing paraffin accumulation problems.

It is recommended to further test the paper retrieval efficiency of the SWPSC searchable database on other topics related to oil field operations such as well fracturing, artificial lift methods, and enhanced oil recovery. Out of the 19 reviewed SPE technical papers that provided knowledge on the paraffin treatment methods, there were 5 technical papers on the Heat and Nitrogen generating system (Thermal) and 5 technical papers on Biological treatment method. As a matter of fact, paraffin treatment by Heat and Nitrogen generating system has never been introduced in the SWPSC annual conference in the past. It is further recommended to invite the authors of Heat and Nitrogen generating system and Biological treatment method to the SWPSC conference in future.
REFERENCES


47. Adobe Acrobat Capture® 2.0. This software installation manual is included with a Adobe Acrobat Capture 2.0 software package.


49. Adobe Acrobat 4.0. This software installation manual is provided with the Adobe Acrobat® 4.0 (Education Version) software package.


52. “Membership.” Online. Available WWW: http://www.spe.org/content/1,1116,2,00.html


74. Corney, D. J.: “Advancements In The Use of Magnetics For Controlling Deposits and BS&W in Oil Wells.” SWPSC. Lubbock, TX, 1993.


PERMISSION TO COPY

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Texas Tech University or Texas Tech University Health Sciences Center, I agree that the Library and my major department shall make it freely available for research purposes. Permission to copy this thesis for scholarly purposes may be granted by the Director of the Library or my major professor. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my further written permission and that any user may be liable for copyright infringement.

Agree  (Permission is granted.)

[Signature]

Student Signature    Date

Disagree  (Permission is not granted.)

[Signature]

Student Signature    Date