A FIELD STUDY OF DOWNHOLE MICROBIAL PARAFFIN CONTROL

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ABSTRACT

A safe and effective biological paraffin control technology, based on the use of a mixed culture of naturally occurring bacteria, has been developed by Kiseki Inc. A research program was undertaken to determine the main mode of action of the microbial paraffin control technology. From the initial phase of this study, the results from field studies on 26 oil wells in Alberta are discussed in relation to the use of bacterial counts in the produced fluid as an indication of effective paraffin control downhole.

INTRODUCTION

The term "paraffin deposit" is commonly used in the oil industry to refer to a waxy material which precipitates out of crude oil onto the surfaces of production equipment. This deposit may consist of paraffins, asphaltenes, oil, water, sand and other debris. The heavier paraffins, with carbon number C_{20} and longer, determine the paraffin content of a crude oil. Excessive precipitation of this waxy component on production equipment and at the perforation face will cause production problems. Historically, oil producers have dealt with the paraffin problem by removing or inhibiting deposition by thermal, mechanical and chemical processes. These methods have various advantages and disadvantages which will not be dealt with in this discussion.

During the last five years, Kiseki has treated a large number of wells successfully utilizing biological products for prevention of paraffin problems. This successful approach has also shown significant cost and safety advantages over conventional hot-oiling and chemical solvent treatments.

PRODUCT DESCRIPTION

Kiseki KBC 100 is a dry preparation of several naturally-occurring bacteria species with a cell count of at least 10^8 CFU/g. These bacteria can grow in the presence or absence of oxygen and are termed facultative anaerobic bacteria. It is a well documented that bacteria will metabolize hydrocarbons. Alkanes or n-paraffins can be oxidized resulting in the generation of several intermediate and end products. Oxidation of the terminal methyl group of a paraffin gives rise to an alcohol, followed by an aldehyde and finally a carboxylic acid group. The carboxylated paraffins are termed long chain fatty acids, which can act as surfactants in oil/water mixtures. Because of the low oxygen

content downhole and the short contact time of the crude oil and bacteria in the well, there can be no detrimental changes in the crude oil properties or quality as a result of biological paraffin control treatments.

TREATMENT TECHNIQUE

Collection of pertinent information about candidate wells is the first step in the treatment procedure. This includes production data, mechanical configurations, and a description and definition of the paraffin problem. This data is important in determining the suitability of the well for a biological paraffin control program.

Production Data - Daily oil, water and gas production per day is recorded as well as H_2S concentration, salinity of the formation water and API gravity of the produced crude.

Mechanical Configurations - This includes whether the well is on pump or flowing; fluid level in the annulus; production depth and bottom hole temperature; casing pressure, tubing and casing diameters and weight.

Paraffin Problem Description - Analysis of the paraffin composition is desired as well as the location in the well of paraffin deposition. Current and past paraffin treatments are recorded as well.

On site treating is performed with a small pressure pump. When treating with the KBC 100 product, one to five kilograms of the dry material is mixed on location with brine water. This solution is pumped into the annular space of the well followed by an adequate flush volume of water or brine containing an inorganic nutrients, which includes a nitrogen and phosporous source necessary for facultative anaerobic bacterial growth.

The treatment process is simple yet attention must be paid to wellbore conditions. The frequency of treatment is typically once per month, but may vary from once every two weeks to once every two months depending on production volumes and the severity of the paraffin problem.

APPLICATION PARAMETERS

Field data has been gathered on over one thousand wells. The length of treatment per well varies from a few months to over four years. Success has been measured primarily by comparison of biological treatment results to the problems encountered on a well before initiation of biological paraffin control. Analysis of trends in well response to biological paraffin control programs has helped guide selection of new treatment prospects and treatment methodology. A treatment failure is defined as a wax build up causing a well to plug off or requiring the return to previous treatment techniques without providing an improved wax inhibition program.

Water Cut

Water cuts in excess of 1% are recommended. The bacteria live in the water and it is through contact with the oil/water interface that the bacteria are able to metabolize the available hydrocarbons. Therefore, when the water cut is very low, the bacterial activity is reduced. When selecting wells to treat, one cannot ignore the importance of water. However, this does not rule out dry wells because in some cases a treatment approach is possible which combines biological and mechanical or thermal methods.

Flowing Wells

Some successful applications on flowing wells have been accomplished, but generally, these have proven difficult to treat. This difficulty is due to a number of factors including high flow rate, higher associated gas expansion, lower water cut and mechanical considerations. Extensions to the wax cutting frequency and reduced operating costs can be obtained by treating the well at the end of the production cycle (if on an allowable production scheme) during the shut-in period.

Fluid Level

High fluid levels in the annulus can prevent proper placement of the batch biological treatment at the site of wax deposition. Several well failures have been linked to such high fluid levels. This is especially true in wells producing higher density oils as the density differential between the aqueous treatment fluids and the crude oil narrows. A circulation approach to treatment is recommended rather than a gravity feed when fluid levels are high. Better treatment results are achieved by circulation of the biological mixture to the point of deposition. This can be accomplished by using a pump truck or the on-site pumping system itself.

Hydrogen Sulphide

Hydrogen sulphide can inhibit the bacterial activity. However, many sour wells, which have had severe wax build-up problems have been treated over a one year period where the H_2S concentration in the solution gas is less than 6%. These wells have a low bottom hole pressure. Limited experience has been gained in treating wells with H_2S concentrations greater than 6%. Caution should be exercised when applying a biological paraffin control technique to wells with H_2S concentrations in excess of 6% in the solution gas.

It should be stressed here that neither the biological treatment nor the inorganic nutrient applied to wells can stimulate sulphate reducing bacteria (SRB) activity. In fact, recent field data has shown an inhibitory effect on any existing SRB population present downhole.

Chemicals

The use of scale inhibitors, corrosion inhibitors, and demulsifiers may inhibit the bacteria. The toxicity of a chemical to the bacteria is dependant upon the chemical composition of the product and/or its concentration in the wellbore. Most commonly used oilfield chemicals have been tested by Kiseki and many wells have been successfully treated using chemicals for corrosion and bacteria for paraffin. In some cases the use of bacteria may eliminate the need for additional chemical products. However, one must understand that joint programs may result in a loss of microbial paraffin control efficiency.

Manufacturers Recommendations

Manufacturer recommended tolerance levels should be followed. For example, the salinity tolerances for the powder product system tolerance is 22%. These tolerances may be stretched by application techniques, however, limitations will be met. Successful biological treatment programs have been established in these high salinity wells. Wells with bottom hole temperatures in excess of 80°C (176°F) should be treated with a high temperature microbial product such as KBC 100-80C, because of the adverse effects of these high temperatures on microbial growth. Most oilfield brines have a pH range between 6 and 9, and therefore, pH does not usually pose a problem.

Mode of Action

Definitive studies that demonstrate the mode of action of biological paraffin control have not yet appear in the literature. Several non-refereed papers have appeared that suggest microbial growth downhole is essential (1,3,4,5,9) or that perhaps the microbial surfactant activity in the product is the only active agent necessary (2,6). Straight chain n-paraffins or alkanes can be β-oxidized in an aerobic environment resulting in the generation of several intermediate and end products, primarily fatty acids (8). The fatty acids can act as surfactants to further solubilize oil in water for further biodegradation. These surfactants, if generated *in situ* in the oil well, may act to solubilize accumulated paraffins and to prevent further paraffin crystallization.

The downhole environment in an oil well is primarily anaerobic. It has been assumed by existing microbial paraffin control product manufacturers and users that the metabolic by-products are similar to those produced in an aerobic environment. Preliminary studies on the anaerobic biodegradation of the paraffin, n-hexadecane, by the facultative anaerobic bacterium, *Pseudomonas aeruginosa*, showed that some oxidation of n-hexadecane could occur in the absence of molecular oxygen (7). In these studies, nitrate was shown to be used as the terminal electron acceptor in place of molecular oxygen. It may be that the longer alkane chains in the wax range (i.e., C_{20} and above) are attacked anaerobically, producing long-chain fatty acids. This possibility is being investigated through the ongoing research program

at Kiseki Inc. The facultative anaerobic bacteria in KBC 100 have been selected for their ability to grow on crude oil or hexadecane (a C_{16} n-paraffin) under anaerobic, denitrifying conditions.

Literature from other manufacturers of biological paraffin control products indicates that high (i.e., 10^5 to 10^6 CFU/mL) microscopic bacteria counts (presence test) in produced fluid samples from oil wells is indicative of the product working downhole, but actual counts from treated wells were only in the range of 300 to 1300/mL (5). In this paper we report the results of a six month field study to determine the validity of using bacteria plate counts from the produced fluid (oil plus water) from oil wells under a microbial paraffin control program to determine the potential effectiveness of the treatment and as an indicator of re-application frequency.

MATERIALS AND METHODS

Biological paraffin control

Proprietary loadings of Kiseki KBC 100, determined by individual well production characteristics, were dissolved in clean water supplemented with nutrients to supply nitrate, phosphorous, and trace minerals for anaerobic growth and activity downhole. This mixture was then added to the casing-tubing annulus of 26 test wells, with re-application every 28 days on average. Wells continued to pump during KBC 100 application, so no shut-in period or well circulation time was allowed. Treatments were started during the first week of February, 1992 and continued, for the most part, over a six month period.

Sample collection and preservation

Duplicate samples were taken from the sample valve on each well head, after allowing sufficient flow prior to sampling to obtain a fresh sample. Samples were collected in sterile 120 mL plastic specimen cups, allowing gas to dissipate and foam to settle so that full sample jars with minimum headspace were obtained. Samples were immediately packed in ice (freezer-packs) in coolers and shipped by courier the same day to the Kiseki laboratory for analysis. All samples were plated within 48 hours of sampling. Samples stored longer or at room temperature were found to give inaccurate counts compared to our initial same day field lab counts.

Viable bacteria plate counts

One mL aliquots were taken from the oil samples, which were either emulsions or separate oil and free water phases. Where two phases were present, samples were taken at the oil/water interface. Serial dilutions were made in sterile physiological buffered saline, pH 7.4, to obtain plate counts between 30 and 300 colonies. Aliquots of 0.1 mL of each dilution were plated on Standard Methods Agar (Acumedia™)

supplemented with 0.75 mL of light West Texas crude oil and 0.325 mL of Tween 80 per litre of agar. Initial studies used 5 replicate plates per sample, which indicated that duplicate plates were sufficient for the counting accuracy required in this study. All plates were counted after 24h at 37°C. Any samples yielding counts less than 30 colony forming units (CFU) on the lowest dilution (i.e., neat) was scored as having <300 CFU/mL, the lowest statistically significant number reportable by this enumeration method. This aerobic plate count procedure is normally used in product quality control of KBC 100 and should accurately enumerate any bacteria from application of KBC 100 to the oil wells. Colony morphologies counted were similar to those found in the product KBC 100.

RESULTS AND DISCUSSION

Test Well Characteristics

All test wells were from mature water-flood fields in the Pembina Cardium or Belly River formations of Central Alberta. All wells were of similar depth with bottom hole temperatures in the 38-50°C (100-122°F) range and preliminary gas chromatography analysis showed that all had paraffins primarily in the C_{20} to C_{36} region with total paraffin content estimated from total GC area to be between 21 and 33%. These parameters were not considered to be a factor in treatment success. Oilfield brine salinity or other toxicity was also not a factor.

Sample descriptions ranged from thick emulsions with no free water (5 wells), emulsions over free water (16 wells), light oil over free water (1 well), light oil with no free water (2 wells), and trace of emulsion in water (2 wells). There was no correlation observed between sample description and bacterial counts or KBC 100 treatment effectiveness.

A wide range of production rates (1.5 - 82 m^3/d) and water cuts (1.3 - 97.6 vol%) were selected to determine the effect of these parameters on the effectiveness of KBC 100 microbial paraffin control and on the observed bacteria counts from the produced fluids. The results of the KBC 100 treatments are summarized in Table 1 and Figure 1. The operational notes in Table 1 indicate any changes in the normal well pumping operation that may have affected the microbial treatment.

Xylene squeezed into the oil-bearing formation was done on three wells to dissolve wax plugging the formation sandface in order to increase production. In one well (6-34) this was done the day before the second KBC 100 application, without notification, so that the concentrated residual xylene would have rapidly killed the new bacterial preparation and any bacteria remaining from the first treatment. Similarly, hot-oiling of wells during mechanical workovers of the well were done in some wells early in the treatment program. In some cases this was made necessary as a result of the microbial treatment working too well, causing a significant release of large slugs of wax that previous hot-oiling failed to dissolve. For this reason it is strongly recommended

that each well be hot-oiled to remove as much of the built-up wax as possible before starting a microbial treatment program.

Microbial Paraffin Control Effectiveness

Scoring the observed paraffin control success is difficult at best during a short 6 month treatment project. Success can be judged by the elimination or reduction of hot-oiling or solvent treatments required after starting the microbial treatments. This would be based on the previous service record of each well. Any well that "waxed-off" or "hung-up" due to paraffin build-up after 3 microbial treatments, thereby requiring hot-oiling, displayed "poor" paraffin control. This happened in only 3 of 26 wells (12%). Of these two were very high water-cut and high producing wells, and one was a very low producing well.

A "good" paraffin control rating was given for those wells that displayed one or more of: an increase in production rate, softer or less wax in the pig traps, reduced pigging frequency, reduced amperage on the pump motor, or generally, less operational problems than occurred prior to microbial treatment as observed by the field operators. Ten wells (39%) reported good microbial paraffin control.

A "fair" rating was given to those wells that were responding somewhat, but not to the same extent as a "good" response described above. No wax-related operational problems were observed in these wells during the treatment program. Six wells (23%) were rated as having fair paraffin control. Seven wells (27%) were scored as "inconclusive" for paraffin control. This was a result of operational problems arising during the treatment program that interrupted the treatment schedule or stopped the well pumping for an extended period, or that microbial paraffin control had not been in place long enough for operators to notice a difference from before treatments began.

Overall, from Figure 1 it appears that the best candidates for microbial paraffin control are wells that have production rates of at least 5 m^3/d and water cuts less than 90 vol%, although two wells with higher water cuts were rated as having good paraffin control (15-4 and 5-3, which produce a more waxy oil than the other wells). Tailoring of the specific KBC 100 application, including product and nutrient water loading and treatment frequency, is being studied to improve the treatment effectiveness in wells with production figures outside of this optimum range.

While the scoring of microbial paraffin control effectiveness described above is somewhat subjective, a more quantitative measure of success is not available over a short term. Only when a well stops or production drops due to wax build-up is a paraffin cleaning treatment required. The aim of microbial paraffin control is to prevent or slow the build-up of wax and eliminate or greatly reduce the frequency of costly brute-force wax removal treatments such as hot-oiling or solvent squeezing.

Bacterial Counts as a Measure of Paraffin Control

Table 2 summarizes the aerobic plate count data in relation to the observed paraffin control discussed above. Table 2 attempts to summarize 26 different plots of CFU/mL in produced fluid over a time period of 5 to 6 months. Three distinct plot patterns were observed.

A "scatter" plot is as it sounds, a random count with no apparent trend. Wells giving a scatter plot would have some high counts, but also several low counts, even <300 CFU/mL throughout the treatment program. Most of the scatter plots were obtained with the "inconclusive" wells, indicating a possible effect of pumping or treatment disruption on the establishment of a stable bacterial population downhole. Examples are shown in Figures 2 and 3. Unfortunately, scatter plots were observed for wells in each observed paraffin control category.

An "increasing" plot shows a definite increase in counts from <300 CFU/mL before KBC 100 treatment to at least 10^3 CFU/mL after the last treatment. Examples are shown in Figures 4 and 5. Some wells scored as good or fair were found to give "increasing" plots.

A "delayed" plot shows a long latency period with few or no counts (i.e, <300 CFU/mL) for the first 3 or 4 treatments, followed by a significant increase in counts toat least 10^3 CFU/mL. Examples are shown in Figures 6 and 7. The delayed plots were found in all four observed paraffin control categories.

Samples taken the same day or 1 to 2 days after treatment often gave very high counts, indicating that some of the original bacterial treatment was being produced out of the well. This is advantageous as the spread of bacteria throughout the production string to the battery will provide paraffin control at the surface, which is especially important during the winter months. The gradual increase in cell counts with time and repeated treatments suggests that a stable population of bacteria has formed downhole, probably on the walls of the tubulars in the region were paraffin crystallization normally occurs. Once bacterial populations increased in number, a proportional increase in bacteria would be found in the produced fluid as a result of the shearing action of fluid flow through this region. Field observation by Kiseki, made over the last four years, have found that periodic re-application of KBC 100 and its nutrient package is necessary to maintain an active population downhole.

CONCLUSIONS

The use of viable bacteria counts from produced fluids is too variable to be used as a direct indicator of microbial paraffin control effectiveness. The nature of the heterogenous oilfield samples (i.e., emulsions) may be part of the variability. Sampling an oil/water interface is difficult and may not yield reproducible results if the bacteria are present in micro-colonies. Surprisingly, some light oil

samples without visible free water gave high counts when plated, as did the free water phases. Other similar samples gave very low counts.

The counts are useful as an indicator that the KBC 100 bacteria are surviving downhole. From the "increasing" and "delayed" plots, it appears that more frequent applications of KBC 100 are needed when starting treatment of a new well, in order to get the downhole population to a significant size where sufficient biosurfactant production can effect paraffin control. It is possible that longer term bacteria counts may shed further light into the population dynamics of downhole bacterial growth.

Ongoing research by Kiseki Inc. to identify a valid short-term measure of KBC 100 treatment success is attempting to identify in the treated oil wells, microbial biosurfactants, such as long-chain fatty acids that have been derived from crude oil paraffins.

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Table 1a
Oil Well Data and KBC 100 Treatment Summary

Well ID	Water Cut (vol %)	Total Fluid (m^3/d)	Number of KBC 100 Treatments	Operational Notes	Observed Paraffin Control
8-32	1.3	1.5	6	Xylene squeeze on Day 33	Inconclusive
16-19	0.6	1.7	6	Xylene squeeze on Day 43	Inconclusive
16-29	22.2	1.8	6		Inconclusive
8-28	16.7	2.4	6	Hot-oiled on Day 71	Poor
6-34	56.7	3.0	6	Xylene squeeze on Day 27	Inconclusive
2-18	30.6	3.6	5	Missed treatment due to snow on Day 28	Inconclusive
14-8	67.9	5.6	4		Fair
14-28B	31.0	5.8	5	Missed treatment - workover on Day 56	Good
14-28A	80.0	7.5	6		Fair
16-8	60.0	10.0	4	Much wax released, hot-oiled on Day 2	Good
14-17	60.0	12.5	4		Fair
8-34	88.9	13.5	6	Mechanical workover on Day 71	Inconclusive
14-27	82.8	14.5	6	Mechanical workover on Day 71	Fair

Table 1b
Oil Well Data and KBC 100 Treatment Summary

Well ID	Water Cut (vol %)	Total Fluid (m^3/d)	Number of KBC 100 Treatments	Operational Notes	Observed Paraffin Control
12-25	88.3	14.5	6		Good
12-1	23.6	15.7	5		Good
8-36	81.3	16.0	6	Mechanical workover on Day 28	Fair
2-21	77.2	16.2	5	Missed treatment due to snow on Day 28	Inconclusive
2-11	88.9	22.5	6		Good
8-11	78.3	23.0	6		Good
14-30	90.9	35.2	4	Hot-oiled on Day 103	Poor
8-4	36.7	39.5	5		Good
16-33	62.5	40.0	5	Missed treatment - hot-oiled on Day 28	Good
10-2	90.0	40.0	6		Fair
15-4	91.3	46.0	5		Good
12-36	93.0	60.2	4	Hot-oiled during workover on Day 87	Poor
5-3	97.6	82.0	5		Good

Table 2
Bacterial Counts in Produced Fluids

Well ID	CFU/mL vs Time Plot Type (see text)	Maximum CFU/mL During Last Treatment	Observed Paraffin Control
14-28B	Scatter	1.3×10^3	Good
16-8	Scatter	3.6×10^3	Good
12-25	Delayed	4.1×10^4	Good
12-1	Increasing	1.3×10^5	Good
2-11	Scatter	3.8×10^3	Good
8-11	Delayed	3.1×10^3	Good
8-4	Delayed	5.5×10^4	Good
16-33	Increasing	2.5×10^4	Good
15-4	Increasing	1.2×10^5	Good
5-3	Increasing	5.8×10^3	Good
14-8	Increasing	4.5×10^5	Fair
14-28A	Delayed	3.4×10^3	Fair
14-17	Delayed	2.6×10^3	Fair
14-27	Delayed	5.5×10^3	Fair
8-36	Delayed	2.0×10^4	Fair
10-2	Scatter	4.5×10^4	Fair
8-32	Scatter	6.7×10^3	Inconclusive
16-19	Scatter	4.6×10^4	Inconclusive
16-29	Scatter	1.2×10^5	Inconclusive
6-34	Scatter	<300	Inconclusive
2-18	Scatter	4.5×10^5	Inconclusive
8-34	Scatter	1.7×10^4	Inconclusive
2-21	Delayed	1.7×10^4	Inconclusive
8-28	Scatter	4.6×10^5	Poor
12-36	Delayed	5.9×10^2	Poor
14-30	Delayed	1.4×10^3	Poor

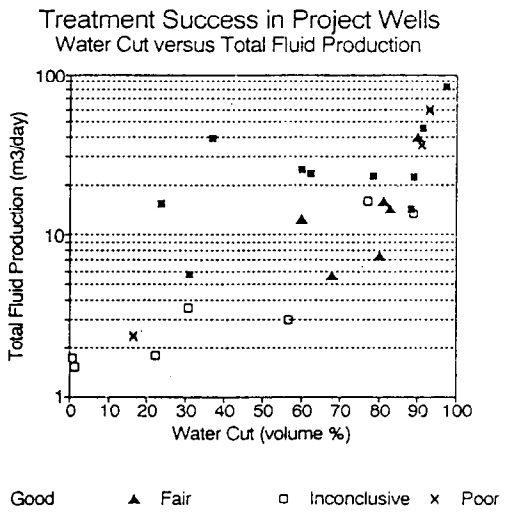

Figure 1 - Summary of total fluid production rate, water cut, and microbial paraffin control in test wells

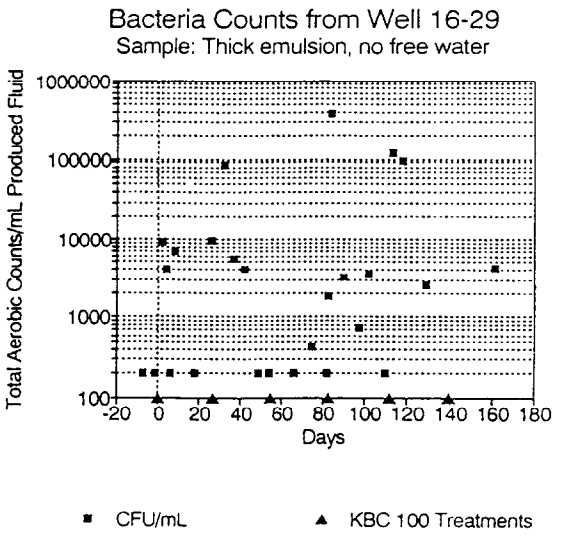

Figure 2 - "Scatter" plot of bacterial counts versus days on KBC 100 treatment

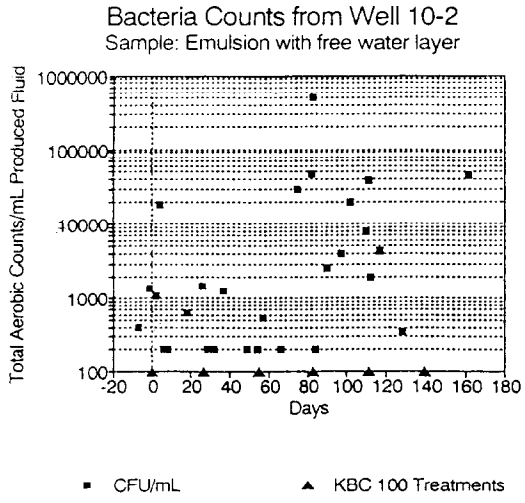

Figure 3 - "Scatter" plot of bacterial counts versus days on KBC 100 treatment

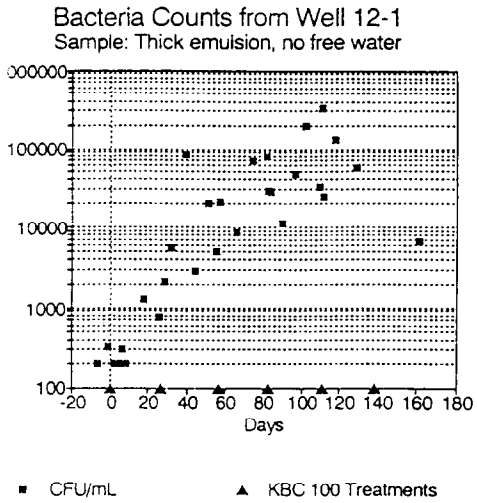

Figure 4 - "Increasing" plot of bacterial counts versus days on KBC 100 treatment

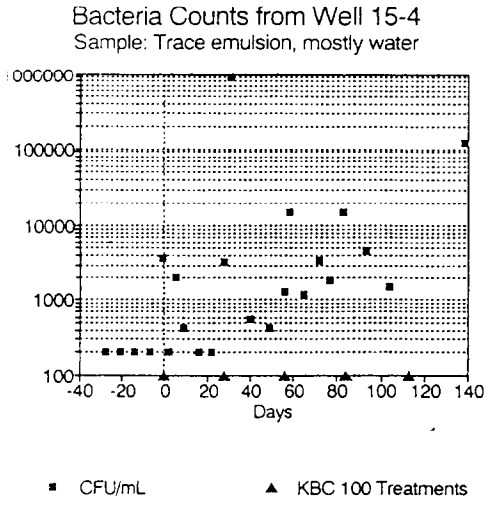

Figure 5 - "Increasing" plot of bacterial counts versus days on KBC 100 treatment