PRODUCTION OPTIMIZATION OF AN OIL RESERVOIR

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ABSTRACT

The production of hydrocarbon fluids is via production system. The production system has different parts with different features. Assurance in optimized performance of this system is requiring precise knowledge of its different parts. The production system can be categorized into three major parts. These are Inflow that related to fluid flow through porous media, vertical well flow (from sand face to the wellhead choke), and flow through surface facility.

By using available models, any part of production system can be modeled. Inflow information of production system such as reservoir pressure and temperature, fluid type and porous media characteristics and vertical well flow information (well geometry and pressure control devices) can be used to model the production system. After modeling of the production system, any problem can be specified and then proper methods are applied to rectify the system.

Selecting proper tubing and wellhead choke sizes are essential to maximize reserve recovery in depletion drive oil reservoirs. In this study two wells of an oil reservoir were analyzed to determine optimum tubing and choke sizes for production optimization. Database bank consists of flowing, static and buildup test were utilized. Data were analyzed with PANSYS and PIPEIM software. Nodal analysis technique was used to analyze tubing and choke sizes for these wells. Also, effects of skin damage change on IPR curve and well deliverability were examined.

INTRODUCTION

The production system can be divided to main three components. These are inflow (fluid flow through porous media), vertical well flow (from sand face to the wellhead choke), and flow through surface facility. In order to optimize the system, any one of these segments must be evaluated separately. Well analysis is the most important step to optimize oil production. The goals of well analysis are to determine the flow rate at which well will produce with a given wellbore geometry and completion configurations (first by natural flow); to determine under what flow conditions the well will produce which can be related to time as the reservoir depletes; to select the most economical time for the installation of artificial lift and to assist in the selection of the best artificial lift method; to optimize the well conditions and system geometry in order to increase produce flow rate; to analyze each component in the well system to determine if it is restricting the flow rate unnecessarily when compared to the flow capacities of the other system components.

The objective of production optimization methods is to find out that component of the well which is restricting the rate below the maximum possible. Well inflow performance relationship (IPR) and tubing performance relationship (TPR) are the basic requirements for well analysis. Accurate well test and flowing data must be obtained then the proper IPR and two phase flow correlation models applied for successful analysis. Then mathematical models of other well components can be used to complete the predicted well performance.

There are many oil and gas wells in an oil field that have not been optimized to achieve an objective
rate in an efficient manner. In fact, many wells had been routinely completed in a manner such that their maximum potential rate cannot be achieved. These wells can be analyzed by applying optimization techniques to evaluate well component such as tubing size and choke size. The effects of change in any one of this component on the entire producing system are very important and can be graphically displayed using well analysis. Tubing size and choke size are important components that must be optimized for production of an oil reservoir. This paper is rating the effects caused by single components on the entire production system using PANSIM and PIPESIM software’s.

### ANALYZING WELL PERFORMANCE

Analyzing well performance is an important step to optimize production by improving production techniques. The analysis can be performed by well tests and examination of the field data. Data gathering was the main problem in this study. For this purpose we selected two wells; A and B in this reservoir with their various data such as flowing, static, PI tests, fluid property and well geometry data. Then PI test data was analyzed by the PANSYS software. The PI tests were done in a short time, therefore they cannot detect the correct magnitudes of skin and permeability and they show only an approximate value of the skin and permeability. Then by using PIPSIME software, tubing size and choke size of these wells were examined. Also for analyzing the effect of inflow performance in the production, skin factor and reservoir pressure were analyzed. Tables 1 and 2 show the well, reservoir and fluid properties data and production condition of the wells A and B, respectively.

### Table 1 - Wells, reservoir and fluid property data

<table>
<thead>
<tr>
<th>Well</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bublpe Point Pressure (psig)</td>
<td>4398</td>
<td>4598</td>
</tr>
<tr>
<td>Bubble Point Temperature (°F)</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>Oil Compressibility @Pp pressure (psi”)</td>
<td>1.45E-5</td>
<td>1.45E-5</td>
</tr>
<tr>
<td>FVF(Bo) @ Pp (bbl/STB)</td>
<td>1.5131</td>
<td>1.5131</td>
</tr>
<tr>
<td>Oil Gravity (”API)</td>
<td>34.9</td>
<td>34.9</td>
</tr>
<tr>
<td>Rr, @ Pp pressure (scf/stb)</td>
<td>1053</td>
<td>1053</td>
</tr>
<tr>
<td>Viscosity @Pp Pressure (cp)</td>
<td>0.2892</td>
<td>0.2892</td>
</tr>
<tr>
<td>Well Radius (inch)</td>
<td>5.504</td>
<td>2.496</td>
</tr>
<tr>
<td>Well Radius (ft)</td>
<td>0.292</td>
<td>0.208</td>
</tr>
<tr>
<td>Average Permeability (%)</td>
<td>13</td>
<td>12.5</td>
</tr>
<tr>
<td>Average S, (%)</td>
<td>24</td>
<td>25</td>
</tr>
<tr>
<td>Type of Completion</td>
<td>cased – hole</td>
<td>cased – hole</td>
</tr>
<tr>
<td>Interval (ft)</td>
<td>11686-11867</td>
<td>12057-12480</td>
</tr>
<tr>
<td>Formation Thickness (ft)</td>
<td>112.5</td>
<td>144</td>
</tr>
</tbody>
</table>

### Table 2 - Production condition of the wells A and B

<table>
<thead>
<tr>
<th>well</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Rate (STB/d)</td>
<td>1000</td>
<td>3000</td>
</tr>
<tr>
<td>Well-bore Flowing Pressure (psig)</td>
<td>3893</td>
<td>4582</td>
</tr>
<tr>
<td>Reservoir Pressure (psig)</td>
<td>4230</td>
<td>4837</td>
</tr>
<tr>
<td>Productivity Index (STB/d/psig)</td>
<td>2.97</td>
<td>12</td>
</tr>
<tr>
<td>Wellhead Pressure (psig)</td>
<td>915</td>
<td>1460</td>
</tr>
<tr>
<td>GOR (scf/stb)</td>
<td>1050</td>
<td>1020</td>
</tr>
<tr>
<td>Gas S.G.</td>
<td>0.77</td>
<td>0.76</td>
</tr>
<tr>
<td>Water cut (%)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Choke Size (1/64 inch)</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

### PI TEST ANALYSIS

#### PI Test of Well A

For this well a PI test was analyzed. The radial flow plot and log-log plot of this test are shown in Figures 1 and 2.
PI Test of Well B

For this well a PI test was analyzed. Radial flow plot and log-log plot of this test are shown in Figures 3 and 4. As shown in these figures, single fault dual-porosity (pseudo steady state) model gives an acceptable match.

Results of the PI tests which are analyzed by PANSYS software, including the skin factor and the reservoir permeability, are summarized in Table 3.

Table 3 - Skin factor and reservoir permeability for Wells A and B

<table>
<thead>
<tr>
<th>Well</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin Factor</td>
<td>7.812</td>
<td>6.5913</td>
</tr>
<tr>
<td>Permeability (md)</td>
<td>301.265</td>
<td>25.2824</td>
</tr>
</tbody>
</table>

ANALYZING THE PRODUCTION CONDITION OF THE WELL A AND WELL B

Flow Correlation Matching

By using flow correlation matching, different two phase flow correlations such as Hagedorn and Brown Revised (HBR), Duns and Ros (DR), Orkiszewski (ORK), Tulsa Hagedorn and Brown (THB), Beggs and Brill Revised (BBR), Original Beggs and Brill (BBO), Govier and Aziz (GA) and Mukherjee and Brill (MB) were selected to predict pressure drop in the wells A and B (Figures 5 and 6).
The production tubing is one of the main components of any production well system. The wrong choice of tubing can lead to disastrous consequences later on during the life of a well and so, the economies of scale need to be properly scrutinized. According to the pressure data of the wells A and B, the following IPR correlations were used: 1- Combination Vogel and PI correlation for the well A 2-Vogel correlation for the well B.

The tubing sizes were varied between 2.2” and 6.184” and all other parameters such as GOR, wellhead pressure, static pressure and etc. for any one of these wells are held constant. Results of analysis are shown in the Figures 7 to 14. Figures 7 and 8 show the IPR and TPR curves for these wells.

Nodal Analysis

Figures 9 and 10 show the IPR and TPR curves for different tubing size of the wells A and B which are developed using nodal analysis.
Figure 9. Tubing size performance analyzing for the well A (nodal analysis)

Figure 10. Tubing size performance analyzing for the well B (nodal analysis)

**Wellhead Performance Analysis**

Figure 11 shows the results of the wellhead performance analysis for well A in two cases; (1) tubing size = 4.276", (2) tubing size = 6.184".

Figure 12 shows the change of flow rate vs. wellhead pressure in the well B for three cases (1) tubing size =2.99" (2) tubing size =3.428" (3) tubing size=3.826".

**Choke Size Analyzing**

For analyzing choke performance, the optimum condition for downstream pressure (P2) was assumed to be equal to 710 psia and 640 psia for wells A and B respectively. Figures 13 and 14 show CPR and WPR curves for wells A and B when the Gilbert and Ashford correlations are used for critical and states.
As shown in the Figure 13, for well A, the predicted operation conditions (q=2200 STB/d and Pwh=1500 psia) differ from real operation conditions (q=3000 STB/d and Pwh=1460 psia). Furthermore, this figure shows that flow behavior in the choke is at sub critical state. But in this well (P2/P1) > 0.55 which shows the flow in the choke is at critical state. Also as shown in Figure 14 for well B, the predicted operation conditions (q=700 STB/d and Pwh=950 psia) differ from real operation conditions (q=1000 STB/d and Pwh=915 psia). Also flow behavior in the choke is at critical condition. But in this well (P2/P1)<0.55 and flow in the choke is at sub critical state.

Reservoir Pressure Effects

For analyzing the reservoir pressure depletion, we assume that the gradient of pressure decline in the reservoir is 40 psig/year. Figure 15 to 16 show the effect of the reservoir pressure depletion on the IPR curves and production rates for the wells A and B, for two conditions: 1- When the wells produced by casing 8.535” 2- When the well A produced by tubing size 4.276” and well B produced by tubing size 2.99”. All other parameters such as GOR, wellhead pressure and etc. were held constant.
Skin Effect

For analyzing the skin effect on IPR curves, pseudo-steady state equation for inflow performance relationship (IPR) were used. Figure 17 and 18 show the effects of skin factor on the IPR curves, for wells A and B.

![Figure 17. Effect of skin factor on the IPR curves for well A(Casing 8.535")](image)

![Figure 18. Effect of skin factor on the IPR curves for well B](image)

CONCLUSIONS

1. Well analysis is an excellent method for showing how the overall well performance optimization and objective flow rate on the oil wells can be done.

2. According to current results, the flow correlation matching for wells A and B, in contrast to measured data, the predicted value for pressure drop (in the wells columns) with the Mukherjee and Brill (MB) correlation is more accurate than other correlation.

3. Achong and the API14B correlations can simulate the choke performance on critical and sub critical conditions of these wells.

4. According to result of tubing size analysis, production rate of these wells via casing 8.535" is at unstable state.

5. The proper tubing and choke bean sizes for well A are found to be 4.276" and 40/64" respectively. By using these tubing and choke bean sizes, the flow rate increases from 3000 STB/d to 4800 STB/d and is at stable state.

6. If the reservoir pressure decreased to 4771 psia, but all other parameters such as GOR, wellhead pressure are held constant, well A cannot produce with the casing 8.535" on natural depletion. But if it is completed with the tubing size 4.274", it can produce until the reservoir pressure decreased to below 4691 psia.

7. The proper tubing and choke bean sizes for well A are 2.99" and 32/64" respectively. By using of these tubing and choke bean sizes, the flow rate increases from 1000 STB/d to 1900 STB/d and production is at stable state.

8. If reservoir pressure decreases to 4164 psia, but all other parameters such as GOR, wellhead pressure and etc. are held constant, the well B with the casing 8.535", cannot produce on natural depletion. But, if it is completed with the tubing size 2.99" it can produce until the reservoir pressure decreased to below 3964 psia.

9. Based on the results of the positive skin effect, the inflow performance cannot be an optimistic one. If the skin damage decreases, inflow performance curves will be improved considerably and the flow rates do indeed increase. Thus, these wells need a cleanup program and stimulation to remove the damage.
ACKNOWLEDGEMENT

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REFERENCES


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EFFECTS OF CONCENTRATION, TEMPERATURE, AND PH ON ANIONIC SURFACTANT ADSORPTION ISOTHERM

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ABSTRACT

The adsorption of commercial anionic surfactant sodium dodecyl sulfate was studied by measuring the surfactant concentrations before and after mixing with crushed samples from Berea cores. Langmuir-type isotherm at equilibrium predicted successfully the equilibrium isotherms determined by static experiments. The main purpose of the study is to determine the effect of concentration, temperature, and pH on adsorption isotherm coefficients (K and \( Y_m \)) in the Langmuir model. Cubic relationships between pH and K, and between pH and \( Y_m \) were observed. Moreover, it was found that the temperature is inversely proportional to the coefficients of the Langmuir isotherm model by a quadratic relationship.

Keywords—adsorption, Langmuir, experiments, temperature, pH.

INTRODUCTION

Surfactants have been used for improving oil recovery for a long time [1]. Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophobic groups (tails) and hydrophilic groups (heads). Therefore, a surfactant contains both a water insoluble (oil soluble) component and a water soluble component. Surfactants will diffuse in water and adsorb at interfaces between oil and water. The insoluble hydrophobic group may extend out of the bulk water phase, into the oil phase, while the water soluble head group remains in the water phase [2]. The “tail” of most surfactants is fairly similar, consisting of a hydrocarbon chain, which can be branch, linear, or aromatic. Surfactants are classified according to polar head group. The anionic surfactant carries a net negative charge in the head group. This charge is mainly responsible for the adsorption of surfactants on solid surfaces. The adsorption of surfactants in the reservoir rock may limit the effectiveness and increase the cost of enhanced oil recovery (EOR) process. It represents a loss of the surfactant from solution, and consequently, a net reduction in the surfactant slug. Therefore, the efficiency will be significantly diminished not only in terms of technical aspects but also in terms of economics.

The mechanism responsible for the surfactant adsorption is mainly the electrostatic attraction between the charged surface of the solid and the charged head group of the surfactant molecule [3]. This is a process of transfer of surfactant molecules from the bulk solution phase to the surface interface. The conventional method of investigating surfactant adsorption on sand is to measure the difference in surfactant concentration before and after equilibrated with sands in static experiments [4].

Many studies have been conducted on anionic surfactants [5], [6], [7]. The adsorption of surfactants from solution is affected by its physical-chemical
properties such as pH [6], [8], temperature [9]. These physical-chemical solution properties can also affect the dissolution behavior of minerals so as to result in significant changes in the precipitation behavior of the surfactants [10]. Sodium dodecyl Sulfate (SDS) surfactant is an anionic organic compound with the formula CH₃(CH₂)₁₁OSO₃Na consisting of a 12-carbon tail attached to a sulfate group. SDS has proved an effective reduction in interfacial tension (IFT) between oil and water which leads to better microscopic sweep efficiency [11].

The objectives of this study are to (1) to determine the effect of concentration, temperature, and pH on anionic surfactant adsorption, (2) to predict the relationships between adsorption coefficients (K and Ym) in the Langmuir model that can account for concentration, temperature and pH changes. To achieve these objectives, an extensive experimental work has been conducted in a wide range of concentrations, temperatures, and pH.

MATERIALS, EQUIPMENTS, AND PROCEDURES

To conduct the experimental work, some materials and equipments were prepared and used. These are: surfactant, alkaline, core samples, and UV light spectrophotometer. In the following, the properties of the materials and description of the equipments are given.

Materials

Anionic surfactant sodium dodecyl sulfate was provided by SIGMA-ALDRICH, which has shown reduce IFT (interfacial tension) effectively. The alkaline additives used to adjust pH were sodium carbonate and sodium metaborate from SIGMA-ALDRICH. Berea sandstones were purchased from BERE A with properties summarized in Table I.

<table>
<thead>
<tr>
<th>Component</th>
<th>Formula</th>
<th>Concentration, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>SiO₂</td>
<td>93.13</td>
</tr>
<tr>
<td>Alumina</td>
<td>Al₂O₃</td>
<td>3.86</td>
</tr>
<tr>
<td>Ferric Oxide</td>
<td>Fe₂O₃</td>
<td>0.11</td>
</tr>
<tr>
<td>Ferrous Oxide</td>
<td>FeO</td>
<td>0.54</td>
</tr>
<tr>
<td>Magnesium Oxide</td>
<td>MgO</td>
<td>0.25</td>
</tr>
<tr>
<td>Calcium Oxide</td>
<td>CaO</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Equipment

Spectrophotometer UV–Visible from SAFAS was used to determine the UV adsorption of sodium dodecyl sulfate (SDS). Calibrations of the absorbency values versus concentrations of surfactant in the solvent of interest were made and the unknown supernatant concentrations interpolated by using Beer’s law [7]. In addition, a simple test tube was employed to perform the static adsorption tests.

Description of test procedures

Static adsorption onto crushed sandstone was determined in batch experiments. One gram of crushed sandstone was mixed with 10 grams of the surfactant solution of different concentrations and varying temperatures and pH. The mixtures were agitated for 24 h then left without shaking for another day to achieve equilibrium, and then centrifuged at 3000 rpm for 20 min. The supernatant liquid was filtered and analyze. The amount of adsorbed surfactant (denoted by Ad in g surfactant/g rock) was calculated from:
where $V$ is the mass (g) of surfactant solution used, $m$ is the weight of the solid sample (g), and $C_0$ and $C_e$ are the initial and equilibrium concentrations of surfactant solution (wt%), respectively. The values of $Ad$ were then plotted against their corresponding $C_e$ values to construct the adsorption isotherms.

Quantitative analysis of SDS solution

For determination of concentration a colorimetric method was used in this study. Beer-Lambert law, which holds for many dilute solutions, states that absorbance is linearly related to the concentration was used (equation 2):

$$A = \varepsilon \cdot b \cdot c$$  \[2\]

where $A$ is absorbance, $\varepsilon$ is the molar absorptivity, $c$ is sample concentration, $b$ is length of light path through the sample (in cm). There is a UV adsorption peak of sodium dodecyl sulfate at 210 nm, which was selected as the detection wavelength for the maximal UV adsorption occurs there. The concentration of sodium dodecyl sulfate can be calculated using Beer’s law (see Fig. 1). The absorbance increases as the solute concentration increases [13].

RESULTS AND DISCUSSION

Adsorption isotherm

An adsorption isotherm is required to predict the amount of adsorption at a certain concentration of the component. The two adsorption isotherms that can be used to describe the equilibrium adsorption are the well-known monolayer Langmuir and empirical Freundlich isotherms [14].

Isotherms are simply plots of the amount of surfactant adsorbed per gram of solid or per surface area of solid vs. the equilibrium surfactant concentration at a constant temperature. It is a measure of the extent of surface area of the adsorbent that is covered by the adsorbent molecules at a given conditions. Results of static experiments for the SDS are shown in Fig. 2.

From Fig. 2, it can be seen that the Langmuir model agrees better with the experimental data in the whole range of test concentration. The Freundlich model gives a good match of the test curve only when concentration is low. The Langmuir adsorption isotherm has been widely applied to many adsorption processes. It has produced a good agreement with a wide variety of experimental data for adsorption of a solute from a liquid solution. A basic assumption of the Langmuir theory is that the sorption takes place at specific homogeneous sites in the adsorbent.
Moreover, when a site is occupied by a solute, no further adsorption can take place at that site [15].

The rate of adsorption to the surface should be proportional to a driving force and area. The driving force is the concentration difference, and the area is the uncovered surface. The Langmuir equation relates solid-phase adsorbate concentration, the uptake, to the equilibrium liquid concentration at a fixed temperature. The Langmuir equation is expressed as [14]:

\[
Ad = \frac{Y_m \cdot K \cdot C_e}{1 + K \cdot C_e}
\]

where \(Ad\) = amount adsorbed (g/g); \(Y_m\) = maximum amount adsorbed (g/g); \(K\) = Langmuir equilibrium constant (dimensionless); \(C_e\) = equilibrium aqueous concentration (wt %).

Equation [3] can be rewritten in the well-known linearized expression of the Langmuir model as follows:

\[
\frac{1}{Ad} = \frac{1}{Y_m \cdot K \cdot C_e} + \frac{1}{Y_m}
\]

Using equation [4] the maximum amount adsorbed \((Y_m)\) and Langmuir equilibrium constant \((K)\) were calculated, and this procedure was employed to find the effect of temperature and \(pH\) on \(Y_m\) and \(K\) in a wide range of surfactant concentrations (0.03-0.21 wt %) going beyond the critical micelle concentration (CMC). Note that the value of CMC for sodium dodecyl sulfate in water (no other additives or salts) at 25°C, atmospheric pressure is 0.18 wt %.

Temperature effects

To determine the temperature effect on the surfactant adsorption, static tests were conducted in temperature range between (25-85°C). High surfactant concentrations were used to improve the accuracy of adsorption estimations. Results shown in Fig. 3 indicate a reduction in adsorption with an increase in temperatures.

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**Fig. 3.** Effect of temperature on SDS adsorption

As can be seen from Fig. 3, an increase in the temperature leads to a considerable decrease in the adsorption of surfactants of high concentration. The lower the temperature, higher the amount adsorbed. These results are in agreement with literature observations [16]. Adsorption means the movement of molecules from solution to solid surface, furthermore at high temperature surfactant solubility is improved [9]. This improvement in surfactant solubility will result in decreasing adsorption at high temperatures, because at high temperature molecules of surfactant prefer to stay in the solution rather than going onto solid surface. To study the effect of temperature on Langmuir coefficients values, plots of \(Y_m\) and \(K\) vs. temperatures were produced (see Figs. 4 and 5).

**Fig. 4.** Effect of temperature on \(Y_m\)
From Figs. 4 and 5, an increase in temperature will lead to a decrease in the values of adsorption coefficients. Although not shown here, different mathematical relationships were tested, among them a quadratic type of relationship was best fitted the changes in $Y_m$ and $K$ as shown in Figs. 4 and 5, respectively.

**Effect of pH**

In chemistry, pH is a measure of the activity of the hydrogen ion, $p[H^+]$, which measures the hydrogen ion concentration. If $pH$ is less than seven means the medium is acidic and if greater than seven the medium is basic. The more the $pH$ is raised, the less positive the surface becomes. The $pH$ effect depends upon the type of the surfactant and its net head charge, anionic SDS surfactant adsorption tend to decrease with an increase in $pH$ [17]. Alkali can decrease the positive charge on the surface of the rock in terms of increasing solution $pH$, as a result adsorption of the negative charged surfactant (anionic) will be decreased. In this study, the effect of $pH$ was in agreement with the literature investigations. Four different initial surfactant concentrations were used. In all cases adsorption was reduced by increasing $pH$, but the reduction was more at high concentration as shown in Fig. 6.

A more detailed investigation of the effect of surface charge ($pH$) on adsorption was carried out by observing the changes in values of adsorption coefficients ($K$ and $Y_m$) while changing the medium $pH$. Without addition of alkali $pH$ of surfactant solution was 7.8. When the value of $pH$ was increased we observed a decrease in values of $Y_m$ and $K$ as shown in Figs. 7 and 8, respectively.
Fig. 8. Effect of pH on $K$

Figs. 7 and 8 also show that adsorption coefficients $Y_m$ and $K$ are related to pH by cubic relationships.

SUMMARY & CONCLUSIONS

In this paper, an extensive experimental work was conducted to study the effects of concentration, temperature, and pH on adsorption. The coefficients in the Langmuir model were adjusted to account for the effects of these parameters for SDS surfactant and sandstone system. The major conclusions can be summarized as follows:

• It was shown that the Langmuir model gives the most appropriate match of the experimental results compare to Freundlich model in the whole range of test parameters for SDS adsorption onto sandstone surface.

• The adsorption of SDS surfactant tends to decrease by increasing the temperature and pH of the medium.

• It was found that the Langmuir adsorption coefficients are related to temperature by a quadratic relationship and to pH by a cubic relationship.

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TREATING PRODUCED WATER FROM AN OIL RESERVOIR FOR RE-INJECTION AND ENHANCED OIL RECOVERY

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ABSTRACT

Water injection is used in the petroleum industry as a means to retain the reservoir pressure and improve oil production. Produced water brought to the surface along with the oil or natural gas can be used as injection water after de-aeration and chemical treatment. Oxygen is removed to reduce the corrosion that can be caused by injection water, and additional chemicals are used for oxygen scavenging. Growing environmental restrictions in some areas of the world are driving treatment and re-injection of produced water. At a minimum, produced water has to be separated from the oil, and the oil often has to be further cleaned before it can be offloaded or transferred into a pipeline. So, produced water must undergo several treatment steps before re-injection. It is quite important to ensure that the water being injected is compatible with the formations receiving the water to prevent premature plugging of the formation or other damage to equipment. It may therefore be necessary to treat the water to control excessive solids, dissolved oil, corrosion, chemical reactions, or growth of microbes. Solids are usually treated by gravity settling or filtration. Residual amounts of oil in the produced water not only represent lost profit for producers, but can also contribute to plugging of formations. The end use of the purified produced water determines the level of water quality required and the methods of treatment. Generally, the energy consumption and operating costs for the treatment are directly related to the ultimate water quality. Deep well injection for disposal or enhanced oil recovery is the most common option for producing water cleaned by current treatment methods. The water must be injected into an isolated formation to avoid any contamination of the groundwater or surface water system. Industry operators usually have their own standards for suspensions and solid contents in treated produced water, because these can cause formation damage. In this paper, we will discuss about treating produced water for re-injection into the oil reservoir.

INTRODUCTION

Oil and gas reservoirs usually have a natural water layer, the formation water, underlying the hydrocarbons. During oil and gas production the formation water will inevitably be produced along with the hydrocarbons. Produced water designates all the waters produced from formations during oil and gas production, constituting the major waste effluent in oil/gas production. Currently, over 90% of produced water is re-injected into the formation, either in support of enhanced oil recovery or for disposal. In arid areas, reclamation of produced water for beneficial uses such as irrigation or tower cooling may be an attractive alternative if the produced water can be purified to an adequate quality, specifically through the removal of dissolved components including inorganic compounds (salts, heavy metals, and radio chemicals) and organic compounds (fatty acid, aliphatic, and aromatics).

One of the major problems a mature field throws up is produced water. The treatment of produced water is a major component of the overheads involved in
producing oil and gas. Wells may start out producing little water, but sooner or later all oil wells produce a much larger volume of water than oil. The ability to efficiently and economically dispose of this water is critical to success in the oil production business. A mixture of performance standards for disposal processes and regulations limiting discharges mandates the standards for treatment of produced water. Produced water can be used as a source of water for water flooding or pressure maintenance projects. If reuse is not an option, produced water is disposed of by discharge into the sea or injection underground.

BACKGROUND

Standards of treatment for reuse are set by industry technical organizations, such as the American Petroleum Institute (API). One of the widely accepted definitions of produced water is the brine brought up from the hydrocarbon bearing formation strata during the extraction of oil and gas, and can include formation water, injection water, and any chemicals added down the hole or during the oil/water separation process. Onshore disposal of produced water is a lot tougher, as regulations are more stringent. The disposal is also energy intensive. The water has to be pumped back into the ground after it has been processed. The core of this problem is the absence of cost-effective technology for the environmentally friendly disposal of water. Traditionally produced water was used to flood wells to get out more oil or used for enhanced oil recovery. But today with polymers serving better purpose, the water is disposed into another well, dug for this purpose. The produced water must be pumped into the ground for safe disposal. The treated water can be put to a number of uses like irrigation for bio-fuel crops, salt-tolerant poplar forest and in the production of mineral products.

As the price of oil and the cost of exploration and production have increased, there is heightened focus in the oil and gas sector on increasing production from existing reservoirs. With large volumes of water used in the production process, water is increasingly moving from an operations issue to one of strategic significance. The oil and gas industry also faces increasing pressure to manage its environmental footprint – including water management offshore. This is even more critical in deeper waters, where water treatment can be extremely expensive – due to footprint and platform weight requirements – and logistically difficult, with limited options and flexibility. As a non-core capability for oil producers, water treatment is often considered the weak link in oil production, in both upstream and downstream operations. These drivers have pushed oil companies to use water more sustainably, driving the concept of water reuse across the industry. As a result, innovative, environmentally focused, and reliable methods of meeting water treatment demands capable of operating in a highly challenging water treatment environment must be developed to meet the growing demand.

To the uninitiated the thought of a gas or oil well is one where a pipe goes down into the ground, and out of it flows either a steady stream of oil or natural gas, that is fed straight into a pipeline and then delivered to them (often at what they consider to be an outrageous price) with no further treatment. Or the crude oil that comes out runs straight over to a refinery where (with minimum effort and maximum profit) it is transformed into the gasoline or diesel fuel that they must then again buy at great cost. The reality of oil and gas production is considerably different, and fluid that comes out of the well is not the ideal that the uninitiated imagines. There are three major fluids that come out of a well, and these are gas, crude oil and water. If the well is a natural gas one, the oil component will not be the heavier fractions that we associate with an oil well, but rather the higher end liquids such as propane and these are referred to as the natural gas liquids.

Produced water is mainly salty water trapped in the reservoir rock and brought up along with oil or gas during production. It can contain very minor amounts of chemicals added down hole during production. These waters exist under high pressures and temperatures, and usually contain oil and metals. The changes in pressure, temperature, and the possible
access to oxygen when the water reaches the surface, means that the water can precipitate out dissolved minerals and hydrocarbons such as paraffin, which can plug wells that are being used for disposal. Early in the life of an oil well, oil production is high and water production is low. As the production age of the well increases, the oil production decreases and the water production increases. When the cost of managing produced water exceeds the profit from selling oil, production is terminated and the well is closed.

Produced water is the largest volume by-product or waste stream associated with oil and gas exploration and production. It is useful to consider the water-to-oil ratios (WORs) and water-to-gas ratios (WGRs) from production activities as this information can be used to evaluate the relative production age of resources within the production lifetime. Because the water has been in contact with hydrocarbon-bearing formations, it contains some of the chemical characteristics of the formations and the hydrocarbons. It may include water from the reservoir, water previously injected into the formation, and any chemicals added during the production processes. The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geologic formation, and the type of hydrocarbon product being produced. Produced water properties and volume also vary throughout the lifetime of a reservoir.

Some of the options available to the oil and gas operator for managing produced water might include the following:

1. Avoid production of water onto the surface – Using polymer gels that block water contributing fissures or fractures or Downhole Water Separators which separate water from oil or gas streams downhole and re-inject it into suitable formations. This option eliminates waste water and is one of the more elegant solutions, but is not always possible.

2. Inject produced water – Inject the produced water into the same formation or another suitable formation; involves transportation of produced water from the producing to the injection site. Treatment of the injected water is to reduce fouling and scaling agents and bacteria might be necessary. While waste water is generated in this option, the waste is emplaced back underground.

3. Discharge produced water – Treat the produced water to meet onshore or offshore discharge regulations. In some cases the treatment of produced water might not be necessary.

4. Reuse in oil and gas operations – Treat the produced water to meet the quality required to use it for drilling, stimulation, and workover operations.

Consume in beneficial use – In some cases, significant treatment of produced water is required to meet the quality required for beneficial uses such as irrigation, rangeland restoration, cattle and animal consumption, and drinking water for private use or in public system. Treatment of produced water has been attempted and is proven to be an effective option for produced water handling. Studies conducted to identify, verify and compile existing and newly developed techniques demonstrate the economic benefits of produced water treatment. Treating oilfield water can help facilitate additional water management options for operators such as beneficial uses that in the short and long term can potentially provide certain community and economic advantages. Treated produced water has the potential to be a valuable product rather than a waste. The treatment of produced water is a necessity before the majority of the conventional produced waters can be applied to other uses. The general objectives for operators when they plan produced water treatment are:

1. De-oiling – Removal of free and dispersed oil and grease present in produced water.


3. Disinfection – Removal of bacteria,
Selection of produced water treatment structure is often a challenging problem that is steered by the overall treatment objective. The general plan is to select the cheapest method – preferably mobile treatment units which assure the achievement of targeted output criteria. In this way technology can be positioned in the field for optimum convenience and the technology can be fine-tuned to meet specific end-uses for the water. The following sections discuss the major objectives of produced water treatment, the alternative technology that is commercially available at the present time, and a summary of the advantages and disadvantages of the various technologies.

PRODUCED WATER TREATMENT OBJECTIVES

Produced water usually represents a waste product in the petroleum industry; it is more often than not only a cost that must be controlled to enhance project economics. Water management and cost control can be done by choosing appropriate water disposal options or by finding an appropriate beneficial use for the water. Waste options and beneficial uses are, however, highly dependent upon water quality and may require water treatment prior to disposal or use. Treatment of produced water may be required in order to meet pre-disposal regulatory limits or to meet beneficial use specifications. If the oil and gas operator aims to utilize a low-cost disposal option such as discharge to surface waters, the produced water must meet or exceed limits set by regulators for key parameters. The parameters might be specific constituents of concern such as ammonia or barium that can be toxic to sensitive animal and plant-life. Or the parameters may be more broadly-based such as Total Dissolved Solids (TDS) or Sodium Adsorption Ratio (SAR) that can affect several aspects of the environment. The regulatory community may make these limits seasonal so that spring run-off water is more carefully protected. In that case treatment options may also be seasonal.

If the oil and gas operator wishes to convey his produced water to a secondary user, the operator must be sure that the water falls within the specifications of the user. Specifications might be chemical (e.g., TDS), physical (temperature), or biological (coliforms per L). Specifications, regulatory limits and produced volume will define treatment objectives for the operator. Produced water treatment objectives may be mandated for several reasons and may be made necessary because of the presence of a number of constituents. The section below discusses some of these common treatment objectives.

METHODOLOGY

The methodology for this paper is depicted in Figure 1. It includes the definition of produced water, introducing methods of treating produced water - discussion about re-injection of produced water into reservoirs, and finalizing results and conclusions.
Treating of Injection Water and EOR / IOR Processes

Re-injection into an underground formation represents the most commonly used approach for management of produced water. Some produced water is injected solely for disposal. Most produced water is injected to maintain reservoir pressure and hydraulically drive oil toward a producing well. This practice can be referred to as enhanced oil recovery (EOR), water flooding, or, if the water is heated to make steam, as steam flooding. In the context of improving oil recovery (IOR), produced water becomes a reusable resource rather than a waste product. In the absence of produced water, operators would need to use other surface or groundwater supplies to conduct the water or steam flood. In typical water flooding cases, when sufficient produced water volumes are not available for injection, other sources of water must be used to supplement the water flooding operation. Historically, fresh water sources have been used for this purpose. Historically, produced water has rarely been injected for EOR at offshore platforms. Several factors account for this divergence from the onshore pattern. First, most platforms are authorized to discharge produced water to the ocean following treatment. Surface discharge represents in most cases the preferred option for operators. Second, at some point in the life of a field (when pressure maintenance is needed), the offshore wells at a platform do not generate sufficient produced water to meet the volumetric needs for water flooding. Third, platforms have ready access to virtually unlimited supplies of seawater. Operators must ensure that the water injected for EOR does not clog the pores of the producing formation. Seawater is nearly always cleaner than produced water, and it requires less pre-treatment before injection. Therefore, seawater generally provides the preferred source of injection water for EOR.

A part of water use in the petroleum industry is related to water flooding into reservoir formations to maintain pressure and to force oil out of the production wells. The general term Improved Oil Recovery (IOR) is used to describe water flood management and any more sophisticated methods aimed at improving recovery. The purpose of IOR is not only to restore formation pressure, but also to improve oil displacement or fluid flow in the reservoir. IOR plays a critical role in tomorrow’s oil production, as existing asset's production dwindles and exploration capital is further stressed. The term Enhanced Oil Recovery (EOR) is a subset of IOR, and includes tertiary methods to increase recovery of oil, ranging from thermal methods, water flood based chemical and microbial addition and gas injection. As the industry responds to pressure to increase oil recovery from existing reserves, novel water-based methods of EOR are gaining acceptance, including Low salinity water flooding as EOR and Chemical EOR (CEOR) water flooding. Increasing oil prices coupled with stricter environmental regulations open the way to improve oil recovery (IOR) concept, which combines advanced EOR techniques, improved reservoir and well management and better production technologies, including controlling injection water quality. Water flooding is known to improve oil recovery, but it also increases water production and the need for treating produced water prior to discharge. The costs of injection-water and produced water treatment increases with the volume of water treated, and by applying a total water management concept, the volumes of water to be treated can be limited to the amount of water needed for injection.
Of all the IOR methods currently in use in oil and gas operations, the most common is water flooding. Historically, there have been two key areas where water treatment has been critically important in water flooding: these are in water flooding filtration, and Sulfate reduced flooding including filtration and membrane treatment. Water is widely used as an injection fluid despite being recognized as having potential value of eroding properties. The most widely recognized problem is scale formation from chemical incompatibility of the injected water and the original formation brine (barium, strontium). In reservoirs which contain a substantial barium or strontium content, high sulfate water injection will cause the naturally-occurring sulfate contained in the water to precipitate with the barium and/or strontium, and can eventually diminish the output of the production wells. Also, sulfate-reducing bacteria in some reservoirs can feed on sulfate in the water, thereby producing hydrogen sulfite and ‘souring’ the well or reservoir. In every EOR operation there are potential sources of damage to wells that can impede their productivity/injectivity. A few factors are mentioned as:

1. Emulsion issues (viscosity increase, oil/water separation, impact of recovery factor, chemical re-use, productivity/injectivity)

2. The key to understanding is how and where emulsions are formed and when they can impact injectivity/productivity and how this can be appraised and mitigated

3. Asphalthene deposition is for mature fields due to reservoir depletion and high water cut, mainly a near wellbore phenomenon with severe well productivity loss as a consequence of wettability alterations, permeability reduction and emulsion stabilization

4. Biofilm formation in the near wellbore area influencing biomass deposition and reservoir souring issues

5. Scaling and precipitation of chemical compounds from co-mingling of waters or alteration of chemical and physical conditions

6. Injection of solids from production wells or formed in transport lines or topside process equipment due to formation of soft scales, corrosion products, etc.

As a result, a mitigating trend in water flooding is the removal of sulfates from water to prevent souring and scaling, referred to as the sulfate removal process. This process involves de-sulfating the seawater using specialized nano-filtration membranes, while maintaining a high salinity. A major challenge with sulfate removal process systems is the significant capital investment for platform space and weight which are required for installation. To retrofit a platform to include sulfate removal process is extremely expensive and may be impossible.

The water chemistry of a produced water sample is not necessarily the same as that of the formation that will receive the injected water. Various substances dissolved in produced water may react with the rock or other fluids in the receiving formation and have undesirable consequences. Before beginning a water flood operation, it is important to analyze the constituents of the produced water for the purpose of avoiding chemical reactions that form precipitates. If necessary, treatment chemicals can minimize undesirable reactions. Bacteria, algae, and fungi can be present in produced water. They can also be introduced during water handling processes at the surface. Bacteria, algae, and fungi are generally controlled by adding biocides or by filtration.

Another aspect which must be considered is that in many cases, low salinity water could result in more effective oil recovery both in terms of the oil production profile and the ultimate recovered volumes. In concept, low salinity injection changes the wettability characteristics of the reservoir rock. In reservoirs with high salinity formation water, injection of low salinity water will generally shift the properties of the reservoirs to a state of water wetness, increasing the microscopic sweep efficiency, and thereby increasing the potential oil recovery. But injection of too low of
salinity water will destabilize the clay minerals which act to bind the oil to the reservoir rock, resulting in clay de-flocculation and formation damage. Also, limestone (carbonate) reservoirs differ in response to low salinity floods compared to sandstone reservoirs, and are more dependent on the ionic make-up of the injection water.

Furthermore, the salinity of the injection water greatly impacts the viscosity, or thickness, of polymer floods used in chemical enhanced oil recovery applications. According to recent studies, when low salinity water is used instead of high salinity water, five to ten times lower polymer concentrations are required to achieve the same enhanced recovery, making polymer chemical enhanced oil recovery a more cost effective EOR process by reducing the polymer, storage, handling and facilities cost. For other chemical enhanced oil recovery processes using alkalinity, it is mandatory that the injection water be softened or desalinated to remove any calcium or magnesium content, in order to prevent precipitation of these constituents as a function of the alkalinity addition. Figure 2 is depicting a common re-injection facility. Water is gathered from a number of wellheads either by truck or pipeline and moved to a central facility where it is usually pumped to a former producing zone for disposal, or pumped to a producing zone for enhanced oil recovery.

**Figure 2. Re-injection facility**

**PURIFICATION OF PRODUCED WATER BY CERAMIC MEMBRANES**

For the purpose of disposal or beneficial reuse, separation technologies need to be deployed for treating the produced water to an appropriate quality for meeting the purposes of disposal and industry uses. Methods for removing suspended solid and oils include gravity separation, gas floatation, and filtration. As petroleum companies initiate more stringent regulations for water disposal and re-injection, removal of suspensions with large particles will be not sufficient for meeting the requirements. Advanced technologies must be developed to remove both fine particles and dissolved components. More stringent water quality is also regulated by petroleum companies for produced water re-injection into low-permeability formations, to avoid or minimize damages to the injectivity. Apparently, the conventional purification processes (i.e., sedimentation and floatation) cannot attain such high standards for water quality. In addition, surface disposal and beneficial uses such as irrigation and tower cooling require removal of dissolved components, which has a major impact on the receiving environment, due to toxicity and corrosion problems. Membrane filtration processes have the potential to generate high quality water by removing suspensions and dissolved components.

Membrane filtration is the most studied process for produced water demineralization and volume reduction. In membrane separation, feed water flows across a membrane surface. Under hydraulic pressure, water molecules permeate through the membrane while particles, dispersed oil, or even ions and organic molecules are rejected through the mechanism of size exclusion. The permeate will be collected as purified water for beneficial uses and the small volume of concentrate with high concentration of salt and organics are disposed of by conventional methods such as deep well injection or evaporation. Membranes can be classified as polymeric or inorganic membranes according to the materials used. Polymeric reverse osmosis membranes dominate the membrane market, but are less efficient for treating wastewater containing strong organic solvents.
and radioactive elements, due to their tendency to degradation and fouling. Porous ceramic membranes have shown promise for produced water purification because of their extraordinary properties, such as thermal stability, high mechanical strength and ease of regeneration after fouling. According to their pore size distribution, ceramic membranes can be classified as micro porous membranes (pore size <2.0 nm), meso porous membranes (2.0 nm ≥pore size ≤50 nm), and macro porous membranes (pore size >50 nm).

A few preliminary studies have indicated that nano filtration ceramic membranes have the ability to separate salt and organics from oil-containing wastewater and oilfield brine. For water desalination using porous inorganic membranes, surface charges play an important role in the separation performance. The electrostatic interaction between ions and membrane surface charge is the main mechanism for electrolyte separation by inorganic nano filtration membranes. Therefore, the factors that affect the surface charge, such as ion valence, ionic strength, and pH, can drastically change the separation performance of micro- or meso porous ceramic membranes. As a result, nano filtration membranes are only efficient for ion removal from low-concentration solutions. In addition, current nano filtration ceramic membranes usually have a wide pore size distribution, which lowers separation efficiency for dissolved components.

Produced water cleaned for beneficial uses, including irrigation, surface disposal, and tower cooling, must meet stringent standards for salinity, total chemical oxygen demand, oxygen biochemical demand, and dissolved organic carbon, which are determined by concentration of dissolved components. Removal of salts and dissolved hydrocarbons by membrane technology is the most promising process for achieving the water quality criteria. Ceramic membranes can overcome many disadvantages of polymeric membranes, i.e., the need for sophisticated pretreatment and their structural instability, as well as limited operating lifetime and thus attract much research interest for produced water desalination.

Membranes technologies show advantages in both energy efficiency and high water quality. Due to the presence of dissolved organics, reverse osmosis with organic membranes is highly limited. Research efforts focus on developing new materials that are less prone to fouling and are easy to regenerate. Ceramic membranes are relatively new classes of material that show promising application in produced water purification due to their extreme stability in harsh environments and optional choices for regeneration.

NITRATE TREATMENT

Produced water can be used as injection water after de-aeration and chemical treatment. Oxygen is removed to reduce corrosion of the injection water system, and additional chemicals are used for oxygen scavenging. If produced water is sulfate rich, removal of oxygen from it also enhance growth of sulfate reducing bacteria which eventually result in reservoir souring due to microbial production of H2S. Traditionally biocides have been used to inhibit microbial growth, in particular growth of sulfate reducing bacteria in the injection water system and the oil reservoir. The traditional efforts to avoid reservoir souring by adding biocides have never been successful. Recently a method for reduction of reservoir souring based on nitrate treatment of injection water has been established. Results showed that addition of nitrate in low concentration resulted in complete inhibition of H2S production and death of sulfate reducing bacteria.

Results from microbial monitoring of the water injection system have shown reduction of sulfate reducing bacteria and concomitant reduction in sulfate reduction rates in the bio-film of the water injection system. Samples from back flooded injection wells where biocide, nitrate and produced water have been injected can be provided. These samples can be analyzed with the objective: To optimize the use of nitrate to reduce reservoir souring during water injection and to evaluate the effect of nitrate treatment during reinjection of produced water. Sub goals have been to characterize microbial population in the oil reservoir water after nitrate treatment of cold
CONCLUSIONS

1. Water supply for drilling, production, IOR, and treatment of produced water are critical challenges for the oil and gas industry, driven by new demands and environmental stewardship. The industry is recognizing that it needs to improve handling of water-related issues and minimize operational water footprint by maximizing water recycling and improving water efficiency. Water treatment is quickly emerging as one of the most significant challenges facing the petroleum industry.

2. Oil companies must use water more sustainably, driving the concept of water reuse across the industry. As a result, innovative, environmentally focused, and reliable methods of meeting water treatment demands capable of operating in a highly challenging water treatment environment must be developed to meet the growing demand. The goals are: minimize operating costs, maximize footprint and energy efficiency, whilst maintaining production and/or increasing oil recovery rates.

3. Re-injection of producing water may result in growth of sulfate reducing bacteria and increased H2S production, so a nitrate treatment method can be used to compensate for the increased H2S level.

4. As field age, the water cut, that is, the amount of water volume produced per oil volume, increases. Therefore the economics are one of diminishing return as less oil revenue is generated and more operating costs are incurred from increased water treatment needs.

5. In chemical enhanced oil recovery, treatment of the resulting produced water is important. Emulsions must be broken down in order to treat and inject the produced water. The chemicals and technologies to accomplish emulsion treatment are sophisticated, requiring a level of treatment expertise.

6. In order to mitigate environmental and economic impacts associated with produced water treatment, one strategy is to purify the produced water for beneficial uses. Inorganic membranes, including microfiltration ceramic membranes and micro porous clay membranes were investigated for purifying produced water to quality adequate for meeting a variety of end use requirements.

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EFFECT OF DIFFERENT VIBRATION FREQUENCIES THROUGH TRACTOR ON MUSCLE ACTIVITY OF DRIVERS

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ABSTRACT

In this study vibration transmitted through the steering wheel of the tractor without any trailer were discussed. An investigation was conducted to determine the transmission of vibration from the steering wheel of the hand tractor to the wrist and upper arm of the operator under actual field conditions during the ploughing of field. The vibration level on the steering wheel was measured and analyzed and the frequency spectra for the chosen working conditions were obtained. Electromyography (EMG) is used to estimate the muscle activity of different hand muscles of the driver. The results indicate that the maximum transmissibility was observed in the first two frequency interval (in Hz) i.e. 1-20 and 20-40, which may harm the operator. The frequency interval was 1-20 (target-wrist), 1-20 (target-upper arm), 20-40 (base-steering), 20-40 (base-steering) and frequency zone was 0.022, 0.3974, 0.2066 and 0.1531 respectively. ECR and ECRB muscle was the most affected muscle found in the forearm system, while operating tractor.

Keywords: LabView, Power spectrum density, Tractor, Vibration, EMG

INTRODUCTION

The term ‘hand-arm vibration’, is frequently used to refer to vibration from power tools, but it does not clearly indicate whether the hand and arm are the origin of the vibration or the limits of its effects [1]. The expression ‘local vibration’ suggests that the effects are localized near to the point of contact with a source of vibration. While some effect can, by definition, only occur in the fingers or hand, the vibration is transmitted further into the body and the effects it produces there may be of interest. It is therefore more satisfactory to refer to hand transmitted vibration, meaning vibration entering the body at the hand [2].

The reviews on the effect of vibration on human health have shown serious evidence of operator ill health that may be attributed to tractor drivers[3]. The frequency range of 2-6 Hz has been observed to be the most harmful for the human operator because resonance occurs within this frequency range [4]. The vibration transmitted from the steering wheel of the small tractor with a 4-wheel drive to the driver’s hands were carried out on the tractor which is randomly chosen from the producer’s store-house. The vibration level has been measured at idling and full load [5]. The vibration level on the steering wheel were measured and analyzed and the frequency spectra for the chosen working condition were obtained [6]. The vibration, which is transmitted from the handle to the hands, arms and shoulders, causes discomfort to the operator and results in early fatigue [7]. An investigation was conducted to determine the transmission of vibration from the handle of the hand tractor to the metacarpal, wrist, elbow and acromion of the operators under actual field conditions during
transportation on a tarmacadam road, rota-tilling in a dry land and rota-puddling in a wet land condition [8]. The maximum transmissibility was observed during the Rota-tilling operation. The work related body pain (WRBP) was maximum during the rota-tilling operation, followed by transportation and rota-puddling.

METHODOLOGY

A LabVIEW code was written to design the instrument for the recording of vibration levels is shown in Figure 1. The data acquisition was made possible using tri axial transducer (model no. SEN041F was made by PCB piezoelectronics, NEW YORK, USA; having 10.23 mV/g,10.66mV/g and 10.41Mv/g sensitives in x, y, z direction respectively, the certificate is enclosed as appendix A)that was connected to NI card (Model No. NI9234 made by National instruments) using lead and the card was interfaced with a Acer laptop (specifications P6000 PROCESSOR, 3 GB RAM).The setup was supportive to the sampling rate of 26,400 per second .However the mean values were only recorded .The recorded data was auto stored in text/excel files in the laptop. The items used in the experimental setup are shown in Figure 2. Procedure to measure the vibration on tractor steering is very much standardized. Vibration measurement on tractor steering have been performed, vibration are measured along z- axis vertical axis. We were using NI USB- 9233 data acquisition device. The USB-9233 consists of two components: an NI 9233 module and aUSB-9162 USB carrier, for vibration measurement, NI USB-9233 connected with personal computer through lead.

Fig 1: The Block diagram of LABVIEW code used for the recording of Vibration levels (in g)
Two integrated electronic piezoelectric (IEPE) sensors are connected to a BNC connector. One of the sensors are attached to the steering (z-base) and the second sensor is attached to the driver’s forearm and upper arm (near shoulder) (z-target). The collected data was processed and analyzed with LabView TM and by using MATLAB programme for each test. The first and foremost subject of the test was given written information about the experiment, which included the purpose of the study. The tractors that were used in experiment - were in working condition, tiers of the tractor for the test were of standard size. Tests were carried out on FARMTRAC 50 model on a field which is shown in Figure 3.

**Fig 2**: The items used in data acquisition process a) Adaptor to hold transducer, b) Triaxial Transducer, c) Data acquisition card and d) Interfacing with Laptop

**Fig 3**: a) FARMTRAC 50 model on a field, b) Sensors position on steering and lower arm (wrist), c) Sensors position on steering and upper arm
Farmtrac 50 from Escorts Ltd. is a 4 stroke, direct injection diesel run tractor with a capacity of 2868 cc. The vehicle comprises of a mechanical constant mesh gearbox with 8 forward and 2 reverse gears. Farmtrac 50 is equipped with a recirculation ball type, worm and nut with double drop arms steering and also has an option of a power steering. The tractor is featured with drum (internal expanding shoe) brakes along with a hand operated parking brake. For measuring vibration, the tractors were moving on a specified field with certain speed. The test was carried out on a tractor without any trailer attached to it but with load attached to it like a ploughing equipment. Subjects were considered to be healthy with no signs of musculo-skeletal system disorders. I am using two sensors for the measurement of vibration in z direction, the first sensor is SEN041F triaxial shear icp accelerometer, this is recognized as a z-base sensor. It was attached to the steering of the tractor Farmtrac-50 to measure its vibration at steering. The second sensor used for the test was 353B18 SN 140184, it was recognized as a target sensor, this sensor was attached to the subject’s forearm and upper arm to measure the vibration transmitted to the hand of the subject.

RESULTS

Tests were carried out on FARMTRAC 50 model on a ploughing field without any trailer attached with it but with a load attached to it like ploughing equipment. The vibration transmitted to hand through steering of tractor was taken by using LABVIEW code with the help of laptop. The recorded data was auto stored in text/excel files in the laptop. Table 1 shows the power spectral density at different frequency zone for z-base on steering.

<table>
<thead>
<tr>
<th>Serial no</th>
<th>Sensor Position</th>
<th>Frequency Zone (Hz)</th>
<th>Power Spectral Density</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Base (steering)</td>
<td>1 - 20</td>
<td>0.1005</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>20 - 40</td>
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<td></td>
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<td>80 - 100</td>
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</tr>
<tr>
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<td>0.0004</td>
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<td>300 - 320</td>
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<td>400 - 420</td>
<td>0.0000</td>
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<td>22</td>
<td></td>
<td>420 - 440</td>
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<td>23</td>
<td></td>
<td>440 - 460</td>
<td>0.0000</td>
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<tr>
<td>24</td>
<td></td>
<td>460 - 480</td>
<td>0.0000</td>
</tr>
<tr>
<td>25</td>
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<td>480 - 500</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
### Table - 2. Power spectral density at different frequency zone for z-target on wrist.

<table>
<thead>
<tr>
<th>Serial no</th>
<th>Sensor Position</th>
<th>Frequency Zone (Hz)</th>
<th>Power Spectral Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Target(wrist)</td>
<td>1 - 20</td>
<td>0.0022</td>
</tr>
<tr>
<td>2</td>
<td>..</td>
<td>20 - 40</td>
<td>0.0000</td>
</tr>
<tr>
<td>3</td>
<td>..</td>
<td>40 - 60</td>
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</tr>
<tr>
<td>4</td>
<td>..</td>
<td>60 - 80</td>
<td>0.0000</td>
</tr>
<tr>
<td>5</td>
<td>..</td>
<td>80 - 100</td>
<td>0.0000</td>
</tr>
<tr>
<td>6</td>
<td>..</td>
<td>100 - 120</td>
<td>0.0000</td>
</tr>
<tr>
<td>7</td>
<td>..</td>
<td>120 - 140</td>
<td>0.0000</td>
</tr>
<tr>
<td>8</td>
<td>..</td>
<td>140 - 160</td>
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</tr>
<tr>
<td>9</td>
<td>..</td>
<td>160 - 180</td>
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</tr>
<tr>
<td>10</td>
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<td>180 - 200</td>
<td>0.0000</td>
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<tr>
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<td>..</td>
<td>200 - 220</td>
<td>0.0000</td>
</tr>
<tr>
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<td>220 - 240</td>
<td>0.0000</td>
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<td>..</td>
<td>240 - 260</td>
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<td>14</td>
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<td>260 - 280</td>
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</tr>
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<td>15</td>
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<td>0.0000</td>
</tr>
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<td>16</td>
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<td>300 - 320</td>
<td>0.0000</td>
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<td>17</td>
<td>..</td>
<td>320 - 340</td>
<td>0.0000</td>
</tr>
<tr>
<td>18</td>
<td>..</td>
<td>340 - 360</td>
<td>0.0000</td>
</tr>
<tr>
<td>19</td>
<td>..</td>
<td>360 - 380</td>
<td>0.0000</td>
</tr>
<tr>
<td>20</td>
<td>..</td>
<td>380 - 400</td>
<td>0.0000</td>
</tr>
<tr>
<td>21</td>
<td>..</td>
<td>400 - 420</td>
<td>0.0000</td>
</tr>
<tr>
<td>22</td>
<td>..</td>
<td>420 - 440</td>
<td>0.0000</td>
</tr>
<tr>
<td>23</td>
<td>..</td>
<td>440 - 460</td>
<td>0.0000</td>
</tr>
<tr>
<td>24</td>
<td>..</td>
<td>460 - 480</td>
<td>0.0000</td>
</tr>
<tr>
<td>25</td>
<td>..</td>
<td>480 - 500</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

### Table - 3. Power spectral density at different frequency zone for z-base on steering.

<table>
<thead>
<tr>
<th>Serial no</th>
<th>Sensor Position</th>
<th>Frequency Zone (Hz)</th>
<th>Power Spectral Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base(steering)</td>
<td>1 - 20</td>
<td>0.1072</td>
</tr>
<tr>
<td>2</td>
<td>..</td>
<td>20 - 40</td>
<td>0.1531</td>
</tr>
<tr>
<td>3</td>
<td>..</td>
<td>40 - 60</td>
<td>0.0470</td>
</tr>
<tr>
<td>4</td>
<td>..</td>
<td>60 - 80</td>
<td>0.0382</td>
</tr>
<tr>
<td>5</td>
<td>..</td>
<td>80 - 100</td>
<td>0.0043</td>
</tr>
<tr>
<td>6</td>
<td>..</td>
<td>100 - 120</td>
<td>0.0003</td>
</tr>
<tr>
<td>7</td>
<td>..</td>
<td>120 - 140</td>
<td>0.0000</td>
</tr>
<tr>
<td>8</td>
<td>..</td>
<td>140 - 160</td>
<td>0.0000</td>
</tr>
<tr>
<td>9</td>
<td>..</td>
<td>160 - 180</td>
<td>0.0000</td>
</tr>
<tr>
<td>10</td>
<td>..</td>
<td>180 - 200</td>
<td>0.0000</td>
</tr>
<tr>
<td>11</td>
<td>..</td>
<td>200 - 220</td>
<td>0.0000</td>
</tr>
<tr>
<td>12</td>
<td>..</td>
<td>220 - 240</td>
<td>0.0000</td>
</tr>
<tr>
<td>13</td>
<td>..</td>
<td>240 - 260</td>
<td>0.0000</td>
</tr>
<tr>
<td>14</td>
<td>..</td>
<td>260 - 280</td>
<td>0.0000</td>
</tr>
<tr>
<td>15</td>
<td>..</td>
<td>280 - 300</td>
<td>0.0000</td>
</tr>
<tr>
<td>16</td>
<td>..</td>
<td>300 - 320</td>
<td>0.0000</td>
</tr>
<tr>
<td>17</td>
<td>..</td>
<td>320 - 340</td>
<td>0.0000</td>
</tr>
<tr>
<td>18</td>
<td>..</td>
<td>340 - 360</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
### Table - 4. Power spectral density at different frequency zone for z-target on upper arm

<table>
<thead>
<tr>
<th>Serial no</th>
<th>Sensor Position</th>
<th>Frequency Zone (Hz)</th>
<th>Power Spectral Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base (steering)</td>
<td>1 - 20</td>
<td>0.3974</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>20 - 40</td>
<td>0.0011</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>40 - 60</td>
<td>0.0006</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>60 - 80</td>
<td>0.0005</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>80 - 100</td>
<td>0.0004</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>100 - 120</td>
<td>0.0004</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>120 - 140</td>
<td>0.0004</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>140 - 160</td>
<td>0.0004</td>
</tr>
<tr>
<td>9</td>
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<td>180 - 200</td>
<td>0.0004</td>
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<tr>
<td>11</td>
<td></td>
<td>200 - 220</td>
<td>0.0004</td>
</tr>
<tr>
<td>12</td>
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<td>0.0004</td>
</tr>
<tr>
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<td></td>
<td>240 - 260</td>
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<tr>
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<td></td>
<td>280 - 300</td>
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<tr>
<td>16</td>
<td></td>
<td>300 - 320</td>
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</tr>
<tr>
<td>17</td>
<td></td>
<td>320 - 340</td>
<td>0.0004</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>340 - 360</td>
<td>0.0004</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>360 - 380</td>
<td>0.0004</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>380 - 400</td>
<td>0.0004</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>400 - 420</td>
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<td>420 - 440</td>
<td>0.0004</td>
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<tr>
<td>23</td>
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<td>440 - 460</td>
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</tr>
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<td>24</td>
<td></td>
<td>460 - 480</td>
<td>0.0004</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>480 - 500</td>
<td>0.0004</td>
</tr>
</tbody>
</table>

### Table - 5. Maximum power spectral density in accordance with the frequency zone (in Hz)

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Sensor Position (in Hz)</th>
<th>Frequency Zone (in Hz)</th>
<th>Power Spectral Density (Maximum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base (on steering)</td>
<td>20 - 40</td>
<td>0.2066</td>
</tr>
<tr>
<td>2</td>
<td>Target (wrist)</td>
<td>1 - 20</td>
<td>0.022</td>
</tr>
<tr>
<td>3</td>
<td>Base (on steering)</td>
<td>20 - 40</td>
<td>0.1531</td>
</tr>
<tr>
<td>4</td>
<td>Target (upper arm)</td>
<td>1 - 20</td>
<td>0.3974</td>
</tr>
</tbody>
</table>
Table 3 shows that when the position of accelerometer is over the thumb phalange of the left hand with the position of EMG sensor on ECRB muscle the maximum value was 762 mV before using gloves and reduced to 442 mV after using gloves. Similarly when the position of accelerometer is over the thumb phalange of the right hand with the position of the EMG sensor on ECRB muscle the maximum value which was 480 mV before using anti vibration pads reduced to 326 mV after using anti vibration pads. More electrical activity of ECRB muscles shows that muscle have to do more effort for performing the same piece of work so muscles fatigue will occur soon. Hence with the applications of gloves we reduce the Electrical activity of muscle as shown in Table 3 finally reducing the effort provided by muscles and hence increasing the time of muscle fatigue. With the help of this discussion we can say that after reducing vibrations and in turn Electrical Activity of muscle we can increase the time of performing work.

**TABLE - 6.** Maximum and minimum values of ELECTRICAL ACTIVITY of ECRB muscle (in mV).

<table>
<thead>
<tr>
<th>POSITION OF EMG SENSOR</th>
<th>VALUES</th>
<th>ELECTRICAL ACTIVITY WITHOUT GLOVES (in mV)</th>
<th>ELECTRICAL ACTIVITY WITH GLOVES (in mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECRB MUSCLE</td>
<td>MAX.</td>
<td>762</td>
<td>442</td>
</tr>
<tr>
<td></td>
<td>MIN.</td>
<td>-487</td>
<td>-487</td>
</tr>
<tr>
<td>ECR MUSCLE</td>
<td>MAX.</td>
<td>480</td>
<td>326</td>
</tr>
<tr>
<td></td>
<td>MIN.</td>
<td>-315</td>
<td>-432</td>
</tr>
</tbody>
</table>

**DISCUSSION**

The vibration transmitted to hand through the steering of the tractor was taken by using LABVIEW code with the help of a laptop. Table 1 shows the vibration level on the steering and Table 2 shows the vibration level on the wrist. Likewise, Table 3 and Table 4 show the vibration level on both the steering and upper arm. The vibration level on the steering and target point wrist and upper arm was measured and analyzed and the frequency spectra for the chosen working conditions were obtained. The results indicate that the maximum transmissibility was observed in the first two frequency interval (in Hz) i.e. 1-25 and 25-50. The frequency interval was 1-25 (target wrist), 1-25 (target upper arm), 25-50 (base steering), 25-50 (base steering) and frequency zone was 0.022, 0.3974, 0.2066, 0.1531 respectively. Table 5 shows that the maximum power spectral density in accordance with the frequency zone (in Hz). It seems that the power spectral density is at the maximum at the target point at the shoulder i.e. 0.3974 in comparison to the target point at the wrist i.e.0.022. The vibration transmitted from the target point at the shoulder was more than the target point at the wrist, as was suggested by [9] that the operators of power tools with frequencies below 25 Hz may experience greater muscles/tissues fatigue and symptoms of musculoskeletal disorder when working with extended arm posture.

ECRB muscle showed the higher values for slope of Median Frequency, EMG work done and RMS value for the EMG activity. Instead of this muscle, ECR muscles had also showed high values for these three parameters (median frequency slope, RMS value and EMG work done of EMG activity but lower than ECRB muscles.

**CONCLUSION**

The following major conclusions can be drawn from the present investigation.

1. The frequency zone 1-20 and 20-40 has given the maximum power spectral density.
(2) In the frequency zone 1-20 for target (wrist) and for target (upper arm) has given the power spectral density 0.022 and 0.3974 respectively.

(3) In the frequency zone 20-40 for base (steering) has given the power spectral density 0.1531 and 0.2066.

(4) The frequency zone 1-20 and 20-40 were the most harmful frequency zone for tractor driver because resonance occurs within this frequency zone and drivers may experience greater muscles/tissues fatigue and symptoms of musculoskeletal disorder when working with extended arm posture.

REFERENCES


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