Optimized Matrix Acidizing Treatment Design to Enhance Well Productivity in Sandstone Reservoirs

Obinna O. Ukpai and Okorie Agwu
Department of Chemical and Petroleum Engineering
Faculty of Engineering, University of Uyo, Uyo Akwa Ibom State, Nigeria
Corresponding author's email: ukpaiobinna3@gmail.com

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ABSTRACT

The use of matrix acidizing (mud acid) stimulation techniques to boost reservoir production rate is one of the primary goals of petroleum engineering program. A popular stimulation technique involves treating sandstone reservoirs with mud acid (HF and HCL) to reduce formation damage. The optimization procedure, however, receives little focus. In this work, an improved stimulation strategy is presented, and the effect of acid volume on productivity index, formation skin factor, and treated zone radius is assessed. From the results obtained in this study, it was discovered that altering the acid volume led to a noticeably greater increase in productivity index and acid treated zone with a decrease in formation skin factor. A petroleum engineering software PROSPER was utilized to design, optimize, and to assess the well performance both before and after acidizing. The software also utilized literature review data on production history. Additionally, the most effective amount of acid was pumped into the formation to reduce the formation skin factor while still retaining the tensile strength of the reservoir rock. When comparing the optimization findings, acid volumes of 500, 800, and 1000 gallons produced productivity indices of 5.3, 5.39, and 5.42 stb/d/psi, respectively, from a productivity index decline of 2stb/d/psi, which represents a considerable increase. Using mud acid concentrations of 5% HF and 15% HCl, the formation skin factor dropped linearly from the initial positive skin of 5 to -0.85.

Keywords: *Stimulation technique, sandstones reservoir, optimization, productivity index, acid volume, formation skin factor, software, mud acid*

1. INTRODUCTION

Alwan (2016) defined optimization as a key tool for obtaining necessary parameters. Optimization of production processes is a significant component in petroleum fields for increasing production rates and lowering production costs. In the last 20 years, there has been a significant advancement in the development of oil and gas prospects using formal optimization approaches (Aronofsky, 1983)

Sand-sized mineral fragments or rock fragments make up the majority of the sedimentary rock known as sandstone. It is a typical rock type that may be found all over the world. It frequently forms in environments with heavy sand buildup, such as deserts, riverbeds, or coastal regions. Sandstone is a type of sedimentary rock known as clastic. It is also referred to as arenite occasionally. Silica, SiO_2, and a variety of silicate minerals make up sandstone reservoir. A sandstone matrix primary constituents include quartz, feldspar, and various kinds of clay (Hong and Mahmud, 2018). Sandstone is an important reservoir rock in the petroleum industry because of its ability to be porous and permeable, which allows it to hold and transfer fluids like water or oil (Muecke, 1982).

Sandstone stimulation technique is a widely used approach in sandstone reservoirs to increase the permeability and porosity of a bottom-hole well (Hong and Mahmud, 2018). In order to regain the permeability of the sandstones, removing skin or increasing permeability around the wellbore, acid solution is injected into the formation as part of the treatment (Guo *et al.,* 2007).

After many years of oil and gas production, many acids have been devised to revive depleted sandstone reservoirs. Acid is a key component in improving a reservoir formation porosity and permeability. Hong and Mahmud (2018) concluded that other acids besides mud acid (HF: HCL) are also used to acidize sandstone. The petroleum sector has expanded its use of chelating agents, fluoroboric acids (HBF_4), and organic acids for the purpose of acidization, according to a literature review.

Melo and De Oliveira (2013) used CFD (computational fluid dynamics) software to build an empirical wormhole propagation model concentrating on the optimization of acid placement through the simulation of various pumping tactics for matrix acidizing treatments. The study also showed how CFD could be an effective technique for dealing with issues near wellbore.

Maltcev and Shcherbakov (2020) presented a study that uses a scientifically based methodology throughout all phases of the well stimulation program, starting with the identification of the type of formation damage, choosing wells that are candidates, and concluding with the design of the matrix acidizing and the processing of results.

Osuala *et al.* (2022) provided a mathematical model that estimates volumes for reservoirs with flow geometries that differ from linear and radial. It was created to assist in the introduction of a new geometry that would contribute to the accountability of complex and diverse reservoirs.

Afsar*et al.* (2022) used a two-scale continuum model to build a mathematical model to assess the acidization of sandstone wells using mud acid and additives.

Xie *et al.* (2023) modifying the four-parameter model, described by (Bryant, 1991), developed a multistage reactive-transport model for fractured sandstone rocks based on the two-scale continuum model together with X-FEM (Extended Finite Element Method) to investigate the impact of fractures on the reactive flow. Blonsky *et al.* (2020) also developed a mathematical model for sandstone reservoirs acidizing treatment system.

2. MATERIALS AND METHODS

The optimization and development of matrix acidizing design for sandstone reservoirs in this study was developed using a petroleum industry-based software known as "PROSPER SOFTWARE". This software was used to model a sandstone reservoir that required stimulation due to formation mineral plugging the pore throat, carry out nodal analysis (to ascertain the vertical lift performance, VLP and the inflow performance relationship, IPR) and to design the matrix acid stimulation treatment.

2.1 Mud Acid Stimulation Treatment Design

The optimized matrix acid stimulation treatment was designed using appropriate reservoir parameters, well parameters, well test data, rock properties and formation composition data as shown in Table1. Sandstone stimulation with mud acid entails pumping hydrochloric acid and Hydrofluoric acid (in the right percentage) into the formation at a pressure below the formation pressure to remove formation minerals that plug the pore throat of the formation.
The software used in this study has an in-built option "stimulation" which aided the development of the mud acid treatment design. Clicking on the "stimulation" option pups up the input data section. Here, the damage type, calculation type and the volume of acid to be pumped into the formation were specified. Other reservoir/well data were also input in this section. Nodal analysis was carried out before and after the treatment to ascertain the effect of acid volume during stimulation of sandstone reservoir, the volume of acid in this study was varied. Consequently, the effect of acid volume on productivity index and damage removal were recorded. The volume of acid used are 50 gallons, 100, 200, 300, 400, 500, 800 and 1000gallons.

2.1.1 Reservoir/Well Data

Acid system and acid volume are one of the most important parameters in the design of acid treatment jobs. Therefore, the acidizing design in this study establishes the impact of acid volume on productivity index, skin factor and the radius treated zone of the well. The optimum volume of regular mud acid system ranges from 125 – 200gal/ft of the formation, Fadhil and Salam (2018).

Table 1: Reservoir/Well input parameters

Parameters	Value
Solution GOR (scf/stb)	800
Porosity, (%)	0.2
Water cut, (%)	0
Oil gravity (API)	37
Gas gravity	0.75
Water salinity (ppm)	25000
Reservoir pressure (psig)	5200
Reservoir temperature (^{0}F)	210
Solution Node Pressure (psig)	500
Overburden pressure (psi/ft)	1.05167
Drainage area (acres)	500
Borehole diameter (inches)	8.496
Perforated interval (ft)	100
Shot density (1/ft)	8
Perforation tunnel diameter (inches)	0.62
Rock bulk density (lb/ft3)	166
Rock tensile strength (psi)	500
Poissons's ratio (%)	20
Permeability (md)	50

3. RESULTS AND DISCUSSION

The designed well in this study had an absolute open flow potential of 18,277.6 stb/day. This from the plot, figure1, is the point where the IPR plot intercepts the X-axis with a corresponding pwf equal to zero. The productivity index of the said reservoir was 5.0 stb/d/psi at the initial stage in the life of the reservoir as shown in Figure2. The operating point, which is the interception between the inflow performance relationship IPR, and the vertical lift performance VLP yields the well deliverability. This tells specifically what the well will actually produce for a given operating condition. From Figure1, the reservoir was producing at an oil rate of 11567.2 stb/day at a pressure of 2800 psig and a reservoir temperature of 217 ^{o}F before the decline in production rate.

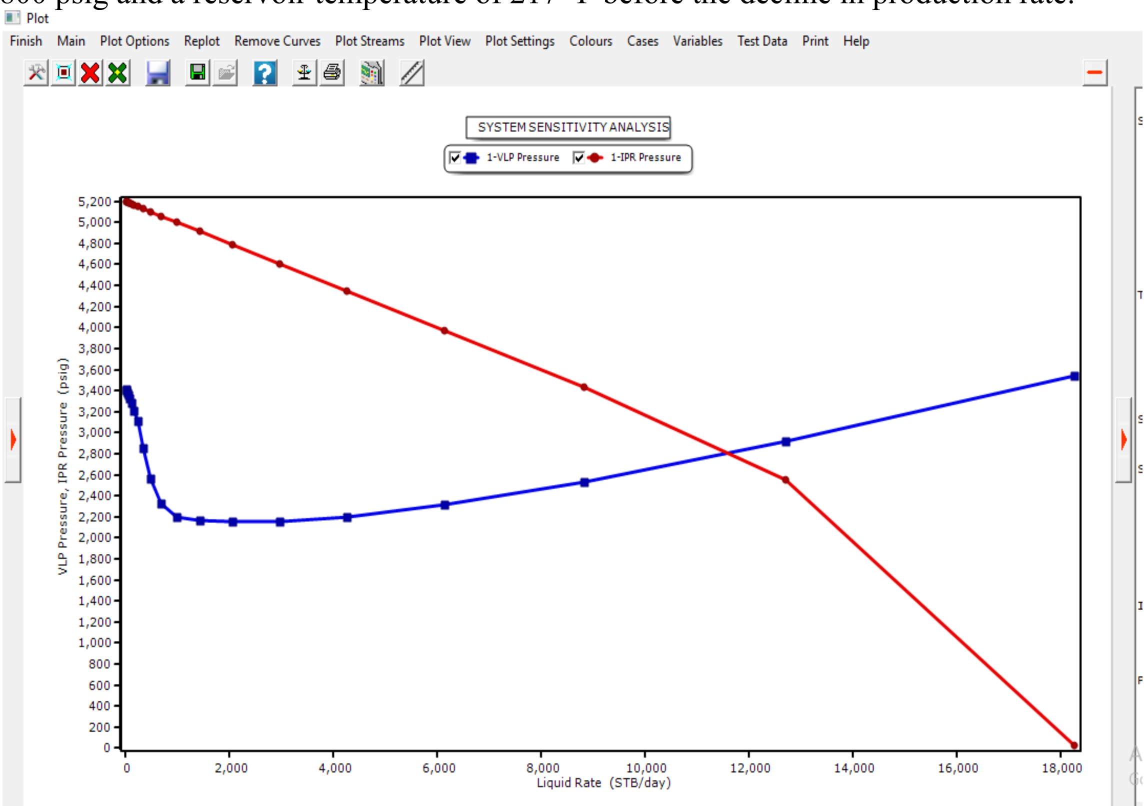

Figure 1: Initial Vertical lift performance vs Inflow performance relationship plot before Production decline

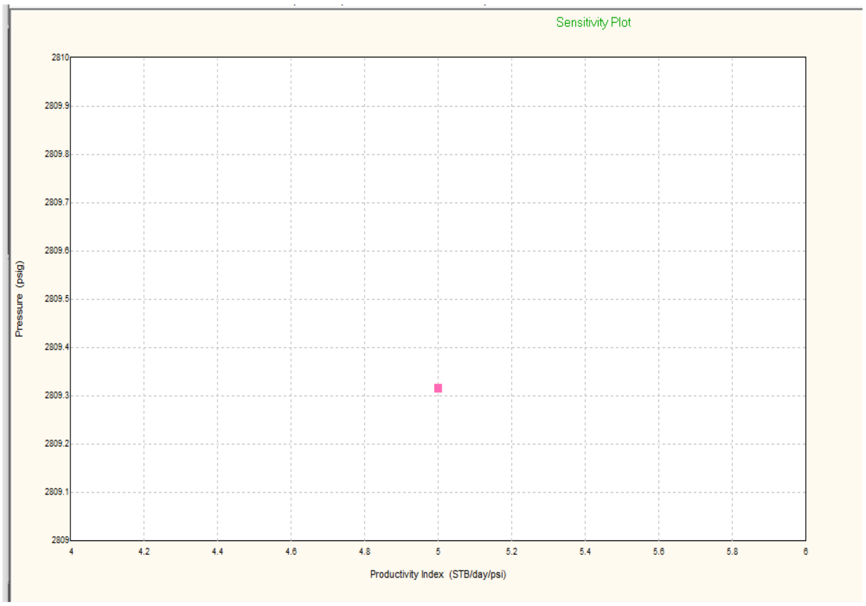

Figure 2: Productivity index plot before production decline

The need for a mud acid treatment design was necessitated by the significant drop in the oil production rate from an initial oil rate recorded at 11567.2 stb/day and a productivity index of 5 stb/d/psi as shown in Figures1 and 2 respectively, declined significantly to 5390stb/day with a proportional decrease in productivity index of 2.0stb/d/psi as shown in Figure3. Hence, the need for stimulation. Sandstone reservoirs are over the years best stimulated with mud acid (HF: HCl) considering the make up the reservoir, cost and the efficacy of the mixture.

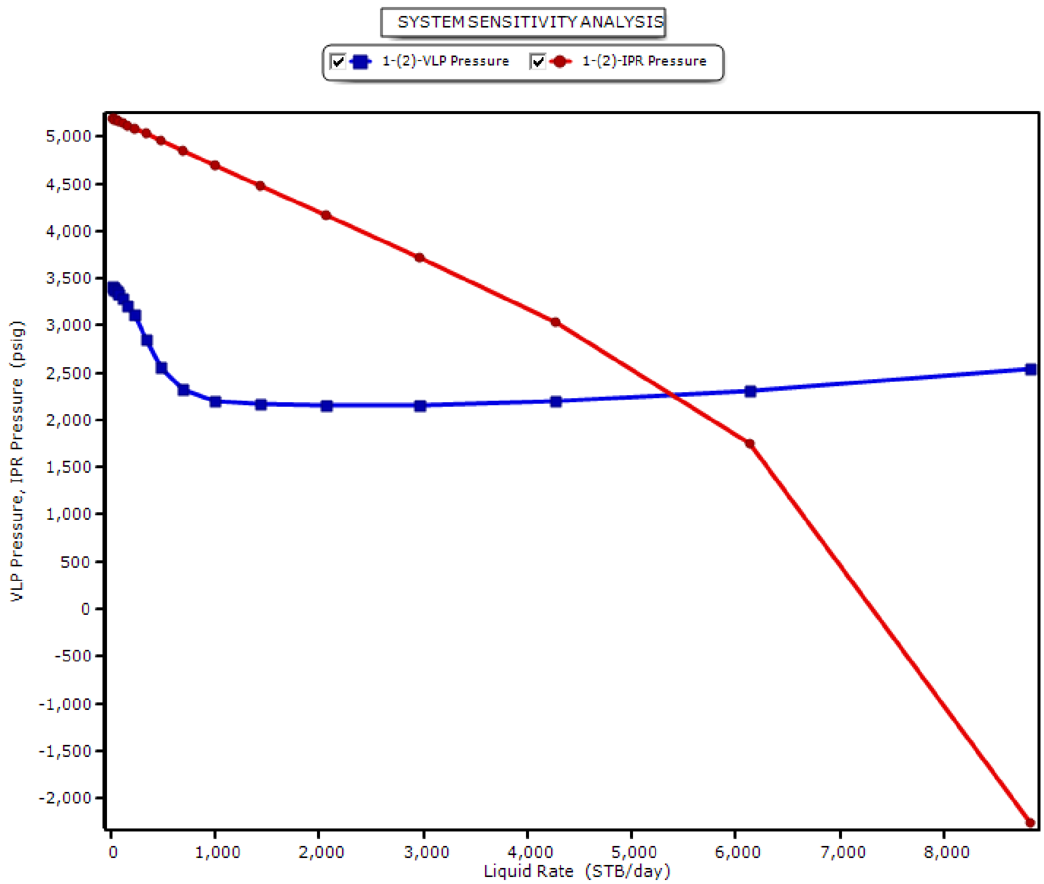

Figure 3: Productivity index plot after production decline

3.1 Optimized Mud Acid Stimulation Design

Acid system and acid volume are one of the most important parameters in the design of acid treatment jobs. Therefore, the acidizing design in this study establishes the impact of acid volume on productivity index, skin factor and the radius treated zone of the well. The optimum volume of regular mud acid system ranges from 125 – 200gal/ft of the formation, Fadhil and Salam (2018). The PROSPER software in its uniqueness analyzed the designed sandstone reservoir based on the input reservoir parameters and determined the optimum formulation based on ionic equilibrium suited for the formation composition. For every volume of acid used, the software calculated the rock properties, treatment results, pumping schedule appropriate for the formation and damage removal as shown in Figure 4.

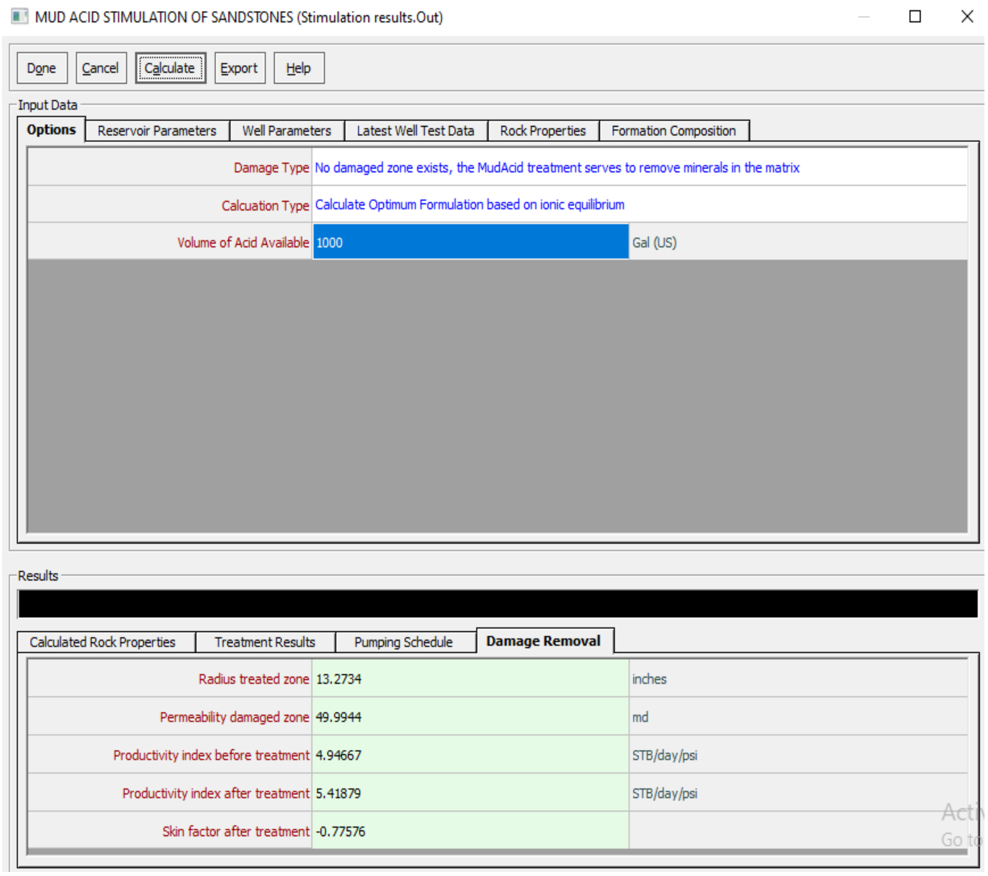

Figure 4: Optimized mud acid stimulation result for 1000gals of acid

3.2 Well Performance After Acidizing

From the optimization results as shown in Table2, it is observed that the relative success of the acid job performed using different volumes of acid ranging from 50 gallons to 1000gallons yielded significant increase in the result obtained.

Productivity index is one of the parameters used in this study to measure the impact of acid volume in the overall performance in the acidizing operation. It is observed from Table2 that there was a liner increase in productivity index as the volume of acid used increased from 50gallons to 1000gallons.The injection of 800gallons and 1000gallons of acid recorded the highest increase in productivity index. This corresponds with works of (Hendrickson *et al*., 1960). Williams *et al.* (1979) assert that acid should be used at the highest rate and in the largest quantities feasible economically. However, contemporary study by Gidley (1985) demonstrated that the acid amount required for a successful treatment is substantially smaller than employed in the petroleum industry ranging from 125 to 200gal/ft.

Table 2: Optimized mud acid Treatment result

Volume of acid (US gals)	Productivity Increase (stb/d/psi)	Skin factor treatment	Radius treated zone (inches)
50	5.17	-0.39	7.57
100	5.22	-0.46	8.44
200	5.3	-0.56	9.53
300	5.31	-0.6	10.3
400	5.33	-0.64	10.9
500	5.35	-0.67	11.4
800	5.39	-0.74	12.6
1000	5.42	-0.87	13.273

Another parameter used in this study to measure the effect of acid volume during acidizing is the skin factor. After acidizing, there was a significant decrease in the skin factor from positive skin of 5 to – 0.39 at an acid volume of 50gallons. This continued to decrease as more volume of acid was injected at different injection rates into the formation as shown in Table2. This agrees with (Rabbani *et al.,* 2018). Hence, skin factor is inversely proportional to acid volume injected into the formation.

Radius treated zone was also observed to have increased proportionally to increased acid volume as shown in Table2. However, excessive acid volume in the formation reduces rock tensile strength. Treating the appropriate damage radius is a crucial component of stimulation success Nnanna *et al* (2009). Gidley determined that the amount of mud acid in a matrix treatment was the primary determinant of its success or failure.

3.3 System Sensitivity Analysis After Acidizing

After the successful mud acid treatment design, a system sensitivity analysis was plotted as shown in Figure. The plot explains the performance and the effectiveness of the acid job. However, the focus is on the three significant productivity indices of 5.35, 5.39 and 5.42 with the corresponding acid volumes of 500gallons, 800gallons and 1000gallons respectively. Considering the initial oil rate, it can be deduced that the acid treatment design effectively performed up to expectation. Production rates increased from 5390.35stb/d to up to 12284.3stb/d (acid volume of 1000gallons) with the corresponding reservoir pressure of 2880psig as shown in Figure 5. Before acidizing, porosity and permeability were recorded at 0.2 and 50md respectively. From the analysis, porosity increased to 0.31 and permeability to 156.69md.

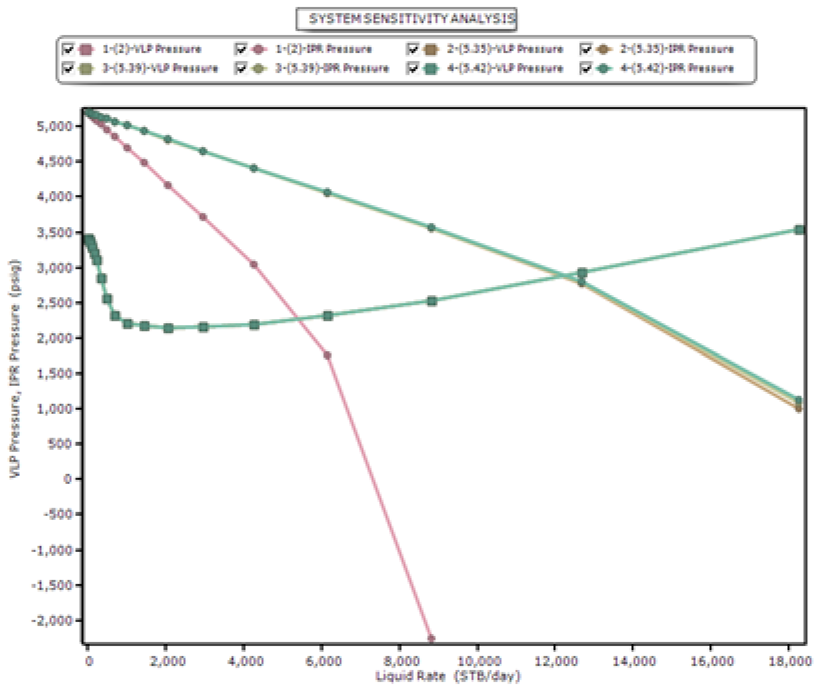

Figure 5: Sensitivity plot

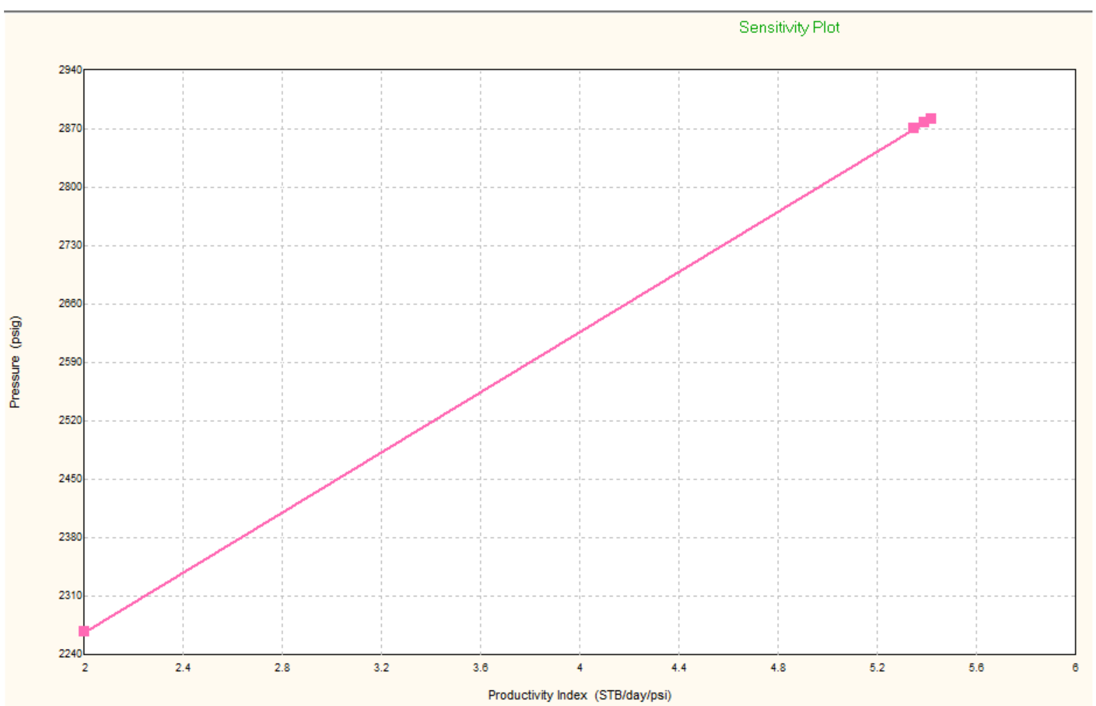

Figure 6: Productivity index plot after acidizing for acid vol. (500, 800 and 1000)

The PROSPER software in its uniqueness analyzed the designed sandstone reservoir based on the input reservoir parameters and determined the optimum formulation based on ionic equilibrium suited for the formation composition. For every volume of acid used, the software calculated the rock properties, treatment results, pumping schedule appropriate for the formation and damage removal. From the analysis, the system in its uniqueness recommended a treatment schedule to be followed for a successful acid treatment job as shown in Table3

Table 3: System Treatment Recommendation

Label	Recommendation
Number of stages	1
Maximum injection rate	8bbl/min
Max. tubing head pressure	5262.27psi/ft
Pump requirement	1070hp
Concentration of HF	5%
Concentration HCl	15%

4. CONCLUSION AND RECOMMENDATIONS

Optimized matrix acidizing design to enhance well productivity in sandstone reservoirs is a stimulation technique aimed at increasing the productivity index of oil wells with low production rates due to formation mineral plugging the pore throat of the formation. This was achieved by injecting different volumes of mud acid into the formation at pressure lower than the formation fracture pressure. The design allowed for different acid volumes to be injected into the formation and the impact on productivity index and skin factor, recorded.

From the results obtained in this study, it becomes obvious that;

Matrix acidizing as a stimulation technique is usually employed to stimulate the well to remove formation minerals plugging the pore throat of the formation, thereby increasing the productivity of the well and reducing formation skin factor for positive economic gain. This approach is especially needed when the reservoir can no longer produce optimally.

In this study, the acid treatment job was designed using PROSPER software which helped optimize the volume of acid used and also in the stimulation of the well. The use of nodal analysis and sensitivity analysis were helpful in achieving the result in this study. Plots from the nodal analysis used inflow performance relationship and vertical lift performance to analyze the reservoir in order to determine the optimum mud acid (HF and HCL) concentration, injection rate, tubing head pressure, number of flushes per stage, and pump requirement.

This therefore, solved the problem of over pumping of mud acid into the formation which reduces the tensile strength of the of the reservoir rock and also solve the problem of primary and secondary reactions during acidizing. From the optimization results obtained in this study, the recommended acid volumes (500, 800 and 1000gallons) gave a higher corresponding increase in production rate (12167.3stb/d, 12251stb/d and 12284.3stb/d) and are recommended for adoption in the petroleum industry based on financial capability and budget.

4.1 Recommendations

The following recommendation is made based on the result obtained in this study.

i. The optimized matrix acidizing design developed in this study should be made available in the petroleum sector for evaluation and possible adoption during stimulation.
ii. Further studies should also be carried out using well data of a severely damaged reservoir to ascertain the consistency of the software in acid treatment jobs.

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