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Development of an Advisor Auditor Computer Program for the Acidizing Operation Design

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Abstract

Acidizing operation is an irreversible process and may cause a serious problem if carried out in a wrong manner. It may fail due to many reasons such as: bad design, poor quality control or any operational problems. The acidizing operation depends mainly on field experience: there is no systematic methodology for the evaluation of the acidizing programs design.

This paper presents a new developed computer program (acidizing auditor advisor program: AAA program) that can be used as an auditor and advisor to evaluate the design of the acidizing operations before its implementation. The developed program can be also used to recommend proper design conditions to achieve successful acidizing operations. AAA program has been tested, validated and applied. It has been used to audit the design of eight acidizing programs.

This work presents the results of the application of AAA program in only three acidizing operations. It was found that the results of AAA program are consistent with the performance of the actual acidizing operations. It successfully predicts the behavior of the acidizing operations and it recommends the necessary preventive actions to mitigate the reasons of any failure. Therefore, it saves time and money, and reduces the risk of acidizing operations failure.

Keywords

Acidizing; Acidizing Auditor Program; Acidizing Operation Design; Stimulation

Introduction

Acidizing is a chemical stimulation technique involving the injection of an acid solution at pressure below the fracture pressure of the formation to remove the formation damage, restore the permeability to its original state and enhance the flow by creating new passes (Civan, 2000).

Commercial application of acidizing occurred in the Gulf Coast of Mexico in 1940, when Dowell introduced mud acid (mixture of hydrochloric acid, HCl; and hydrofluoric acid, HF). Following this event, the application of acidizing has grown rapidly and developed as follows (Ahmed, 2011):

- During 1950s and 1960s, the application of acidizing expanded and numerous acid additives and systems were developed.
- During 1970s and 1960s, the work on the physics of acidizing in limestone and the secondary reactions of sandstone acidizing have been performed. Foam diversion, oil soluble resins and coiled tubing placement were introduced to improve zone coverage. The emphasis for clay problems shifted from clay swelling to clay migration. Numerous clay control agents were developed.
- Since 1990s till now, environmentally friendly additives have been introduced and better understanding of the acidizing chemistry has been achieved. In addition, a lot of research has been performed to study all phases of the acidizing process: candidate selection, treatment design, monitoring of the execution (real-time evaluation of skin effect evolution) and post-treatment evaluation.

Acidizing Auditor Advisor (AAA) Program

To achieve good acidizing operation design, several types of data should be accurately collected and considered as follows:

1. Well data including well deviation, completion type, minimum inside diameter, completion size, flowing bottom hole pressure, tubing end, perforated interval, tubing volume, casing volume, and total depth;
2. Production data including gross production rate, water cut, productivity index, specific gravity, gas lift mandrel on/off, H2S content, oil viscosity, and oil formation volume factor;

3. Reservoir data including skin factor, reservoir permeability, drive mechanism, formation porosity, reservoir pressure, fracture pressure, gas oil contact, reservoir temperature, damage radius, and reservoir radius;
4. Mineralogical data including formation type, clays types and percentages, formation damage type, and cementing material;
5. Historical data including drilling fluid and last operation executed; and
6. Lab data including solubility and compatibility tests (emulsion and sludge tendency).

Generally, previous experiences and analogy concept are used to design the acidizing programs. This work presented a developed computer program (AAA program) that can be used as an auditor and advisor to evaluate the design of the acidizing operations before its implementation. AAA program was developed in Visual Basic Language Version 6. Fig. 1 shows the flow chart of this program which mainly consists of five steps as follows:

1. The first step is "Data Entry of the Candidate Well" in which the data of the candidate well (well data, production data, reservoir data, and mineralogy data) is fed to AAA program. Fig. 2 presents, as an example, the interface of this step in the developed program.
2. The second step is "Data Entry of the Proposed Acidizing program" in which the data of the proposed acidizing program (acidizing technique, design steps, placement technique, volume of acid, type and quantities of additives, pumping pressure, and pumping rate) is fed into AAA program.

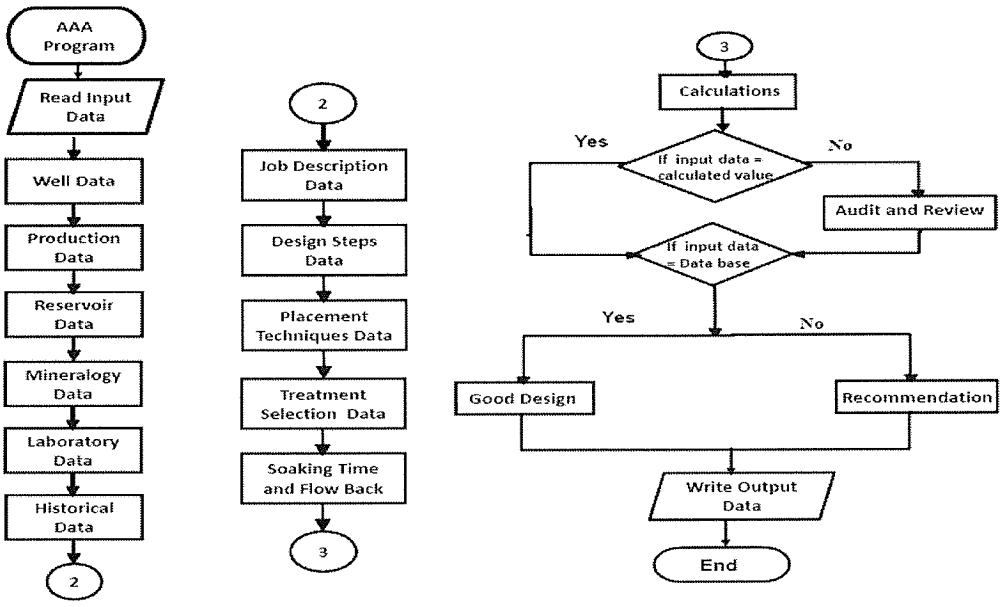


FIG. 1 FLOW CHART OF AAA PROGRAM

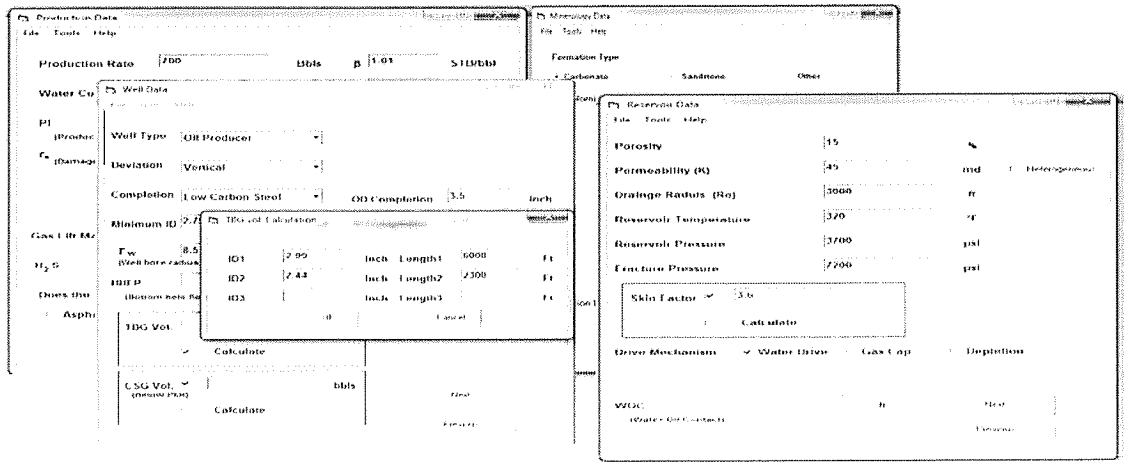


FIG. 2 INTERFACE OF AAA PROGRAM

TABLE 1 MODEL EQUATIONS

No.	Equation
1	$Q_{max} = \frac{4.916 \times 10^{-6}\ Kh\ (P_{frac} - P_{res} - P_{safe})}{\left(\mu B \ln \frac{r_e}{r_w} + S\right)}$
2	$Q_{min} = \frac{(Vol_{acid} - Vol_{pump})}{42 \times 60\ t_{cI}}$
3	$P_s = P_{frac} + P_{fric} - P_{hyd} - P_{safe}$ $P_{fric} = 518 \frac{\rho^{0.79} q^{1.79} \mu^{0.207}}{ID^{4.79}}$ $P_{hyd} = 0.052 \times \rho d \times h$
4	$Vpickling = 4.68743 \times t_s \times L \times F \times (ID + t_s)$
5	$V_{tbg} = \frac{ID^2}{1029} \times L$
6	$S = \left(\frac{K}{K_d} - 1\right) \ln \frac{r_d}{r_w}$

β: Formation volume factor of the injection fluid, res bbl/STB;
D: Inside diameter, in;
F: Safety factor, (1.1 is assumed);
h: Net height of the formation, ft;
H: True vertical depth, ft;
ID: Inside diameter, in;
k = Undamaged permeability, md;
k_d = Damaged permeability, md;
L = Length of tubing, ft;
P_{safe}: Safe margin, 200 to 500 psi;
P_{frac}: Fracture pressure, psi;
P_{fric} : Friction pressure, psi;
P_{hyd}: Hydrostatic pressure, psi;
P_{res}: Average reservoir pressure, psi;
P_s : Well head pressure, psi;
q: pumping rate, bbl/min;
Q_{max}: Max injection rate, bbl/min;
Q_{min}: Minimum allowable pumping rate, bbl/min;
R_d = Damage radius, ft;
r_e: Drainage radius, ft;
r_w: Wellbore radius, ft;
S: Skin factor, dimensionless;
t_{cI} : Corrosion inhibition time, hr.;
t_s : Thickness of mill, in;
Vol_{acid}:Total acid volume, gal;
Vol_{pump}: Total pumped acid, gal;
$V_{pickling}$ = Pickling volume, gal;
V_{tbg}: Tubing volume, bbl;
μ: Viscosity of the injection fluid, cp;
ρ: Fluid density, gm/cc; and
ρd: Fluid density, ppg.

3. The third step is "Calculations". Calculations step is one of the major steps in the AAA program which assesses the values fed in the first and second steps. During this step, AAA program calculates the maximum pumping pressure, minimum pumping rate, maximum pumping rate, pickling volume and skin. The relevant equations for the model calculations are presented in Table 1 (Ahmed, 2011; Al-Mutairi and Nasr El Din, 2005; Al-Mutairi et al., 2005; Economides and Nolte, 1989; Muecke, 1982).

4. The fourth step is "Evaluation and Modification". During this step, AAA program compares (a) the data of the candidate well and the proposed acidizing operation, and (b) the screening criteria of the acidizing operations in the database. In this step, the causes of the unsuccessful design are defined. The comparison is carried out according to specific database on AAA program. The database includes screening criteria for the data of the well, reservoir, production, mineralogy, lab, and concentrations range of the acid additives. Tables 2 to 7 present a summary for these screening criteria (Ahmed, 2001; Ahmed, 2011; Al-Mutairi and Nasr El Din, 2005; Al- Mutairi et al., 2005; Al-Mutawa et al., 2003; Buijse and van Domelen, 1998; Chang et al., 2007; Civan, 2000; Economides and Nolte, 1989; El-Halib, 2010; Gdanaski, 2005; Guidry et al., 1989; Hill and Rossen, 1994; Don Hill et al., 2000; Jones et al., 2001; Kalfayan and Metcalf, 2000; King, 1996; McLeod, 1989; Muecke, 1982; Sahara Petroleum Service Company Ltd, 2010; Shokry and Tawfik, 2010; Shuchart and Gdanski, 1996; Subero and Holder, 1996; Toseef et al. 2010; Williams et al., 1979). The database has been collected from field experience, acidizing manuals, books, SPE papers, and SPE Monograph Volume 6. The database of the program can recommend the optimum acid volume and the percentage of its additives.

5. The fifth step is "Output Data". At the end of each run, AAA program presents a report concerning the evaluation of the acidizing operation design, as being either "Successful or Unsuccessful". If the proposed acidizing design is unsuccessful, the report highlights the reasons of the failure and proposes the alternative solutions to adjust and improve the acidizing design.

TABLE 2 SCREENING CRITERIA OF THE WELL DATA

Property	Parameter	Actions / Recommendations
Well type	Oil well	Flow back step should be executed.
	Water well	Flow back step should be executed. If flow back step will be cancelled and the solubility test is 100 %, the over-flush volume should be duplicated.
Completion type	Cr, Ni	Pickling steps should be avoided and use coiled tubing as a placement technique to protect the completion.
Paz zone length	>100 ft	Diversion technique should be used.
Minimum inside diameter (ID)	Coiled tubing outside diameter OD	If outside diameter of coiled tubing is equal or larger than the minimum ID of completion, the coiled tubing string should be changed.
Total depth (TD)	Coiled tubing length	If the coiled tubing technique will be used, the coiled tubing should be taller than TD.

TABLE 3 SCREENING CRITERIA OF THE RESERVOIR DATA

Property	Parameter	Actions / Recommendations
Reservoirtemperature	200 °F >Tres>300 °F	Acid inhibitor aid should be added.
	>300 °F	Organic acid or combined acid should be used.
	T >250 °F	VESCO diversion technique cannot be used because of over limit of temperature.
	T >300 °F	Insute gel acid technique cannot be used because of over limit of temperature.
Reservoir permeability	Heterogonous	The diversion technique should be used.
	Gas reservoir	<1 md, cannot be stimulated.
	Oil or water reservoir	<20 md, cannot be stimulated.
Reservoir. pressure	Less than the hydrostatic pressure	If the reservoir pressure is less than the hydrostatic pressure, the lifting system (such as Nitrogen Lifting or Gas Lifting Mandrel) should be used to flow back the well.
Drive mechanism	Water drive	If the retarded acidizing is used, the water-oil contact (WOC) should be away (greater than 100 ft).
	Gas cap	If the retarded acidizing is used, the gas-oil contact (GOC) should be away (greater than 100 ft).
	Gas cap and water drive	If retarded acidizing is used, the WOC/GOC should be away (greater than 100 ft).
Pumping pressure	Max pumping pressure	If $P_s > P_{frac} + P_{fric} - P_{hyd} - P_{safe}$ Stop operation.

TABLE 4 SCREENING CRITERIA OF THE PRODUCTION DATA

Property	Parameter		Actions / Recommendations
Water cut	>40 %		It is not recommended to stimulate the well.
Format--ion damage	Organic	Paraffin	It does not require a stimulation job; the right solution is mixture of organic solvent and diesel.
		Asphaltine	
	Inorganic	Calcium carbonate	HCl / Organic acid should be used.
		Iron carbonate	
		Iron sulfide	It does not require a stimulation job; the right solution is a mechanical solution.
		Iron sulfate	
		Gypsum	
		Barium sulfate	
		Strontium sulfate	
		Fill	
	Other	Emulsion	It does not require a stimulation job.
		Water blockage	
		Sludge	
		Bacteria	
		Wettability change	
Damage radius (Rd), ft	Rd ≤ 0.5		Matrix acidizing should be used.
	0.5<Rd<1		Acid wash techniqueshould be used.
	1>Rd>3		Regular acidizing technique should be used.
	3>Rd>6		Retarded acid technique should be used.
	Rd>6		
H2S	50,000> H2S > 0 ppm		Add H2S scavenger.
	H2S > 50,000 ppm		From field experiences, coil tubing is not capable to work in this environment.

TABLE 5 SCREENING CRITERIA OF THE LAB DATA

Property	Parameter	Actions / Recommendations
Compatibility data	Emulsion tendency	Demulsifies should be added
	Sludge tendency	Anti-sludge should be added

TABLE 6 SCREENING CRITERIA OF THE MINERALOGICAL DATA

Property	Parameter	Actions / Recommendations
Formation types	Carbonate	Never ever choose HF acid.
		HCl or organic acid should be used.
	Sandstone	If the carbonate content is greater than 15 %, it is recommended to consider the formation as carbonate formation.
		If the carbonate content is less than 15 %: • HF system should be used, and • Pre-flush by HCl or organic acid should be used.
		If HF is used, the pre flush should contain NH4Cl to avoid the contact between HF and formation water.
		If the carbonate content is less than 15 %: • HF system should be used, and • Over-flush by HCl or organic acid should be used.
		Mutual solvent should be added in the over-flush to alert the wettability: change the formation to be water wet.
		If the high quartz content is greater than 80 % and the clay content is greater than 5%, 12:3 HF should be used.
		If the cementing material is carbonate, it is not recommended to use HCl greater than 10%.
		If the high feldspar is greater than > 20 %, 13.5:1.5 HF should be used.
		If the high clay is greater than 10 %, 6.5:1 HF should be used.
		High Iron chlorite Clay, 3: 0.5 HF should be used.
Clays types	Ellite	It is not recommend to use HCl.
	Chlorite	Iron control should be added.
	Semictite	Fresh water should be avoided.
	Kaolinite	Fresh water should be avoided. NH4Cl should be added to avoid a swelling problem.
	Dolomite	It needs more than one hour of soaking time.

TABLE 7 NORMAL CONCENTRATIONS RANGE OF THE ACID ADDITIVES

Property	Additives	Range%
Additives range	Acid inhibitor	0.2>Acid inhibitor >2
	Surfactant	0.1> Surfactant>0.5
	Mutual solvent	5>Mutual solvent>10
	Clay stabilizer	0.1>Clay control >0.2
	NH4Cl solution	2>NH4Cl>5
	KCl solution	2>KCl>5
	Demulsifier	0.1>Demulsifier>0.5
	Inhibitor aid	0.2>Acid inhibitor >2
	Anti-sludge	5> Anti sludge >25
	Non emulsion	0.2> Non emulsion >2
	Emulsifier	1> Emulsifier >4
	Organic solvent/ Acid	30:70
	Iron control	4> Iron control>8
	H2S scavenger	0.5>Anti sludge > 2.5
	Friction reducer	0.1> Friction reducer >0.5
	Foaming agent	0.1> Foaming agent >0.5

Database of AAA Program

The database of the AAA program was collected from the field experience, published data, acidizing manuals, handbooks, and the results of 93 previous acidizing operations. The database represents different basins, well types, and lithologies. 43% of these acidizing operations were executed in Egyptian oil fields; and the rest were executed in the Libyan oil fields. The case studies of the database are classified according to their results as follows: 73% of these acidizing operations represent successful acidizing programs, and the rest (27% of which about 25 are

acidizing operations) represents unsuccessful acidizing programs. There are various reasons for the failure of these acidizing programs. Fig. 3 represents the percentage of the failure reasons in the selected acidizing programs. A brief description of the major failure reasons is listed below:

1. Inappropriate acid type: Some wells are stimulated by wrong acid type. If HF is used in sandstone formation or carbonate formation, severe formation damage may occur from by-product precipitation. Moreover, in high temperature wells, it is not recommended to use HCl more than 15% by weight as it will be highly-corrosive to the metal in the wells.

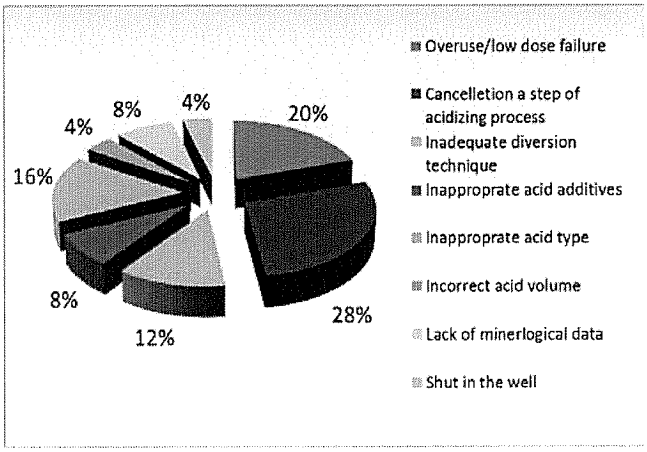


FIG. 3 PERCENTAGES OF THE FAILURE REASONS IN THE SELECTED ACIDIZING PROGRAMS DATABASE

2. Inappropriate acid additives: All additives which are used in the acidizing operations have benefits as well as side effects. If inappropriate additives are used, formation damage occurs.
3. Additive overuse or low-dose: Acid inhibitor is used to minimize the corrosion rate. However, using over-dose of acid inhibitors changes the formation wettability due to the adsorption of acids inside the formation. On the other hand, a low-dose of the acid inhibitor may increase the corrosion rate.
4. Improper placement technique: Two placement techniques are used to pump the acid in the well. The first technique is Coiled Tubing (CT: concentric tube ranges from 1 to 4.5 inch). This technique can be applied to depth of 20,000 ft or more. When the pay zone contains several layers, it is recommended to use CT to spot the acid cross the perforation and reciprocated against the pay zone to make good contribution. The second technique is Bull Heading (BH)which is cheap. The pumping rate with bull heading technique is better than coiled tubing in case of normal conditions.
5. Lack of the mineralogical information: it may cause more damage. If the formation has some types of clays like illite, and the formation is stimulated by 15% HCl, the problem of fine migration shall occur.
6. Cancelation of any step of the acidizing sequence: The acidizing steps sequence are pressure test, pickling, pre-flush, main treatment, over-flush, soaking time, and flow back. Each step has an important role in the acid operation (Al-Mutairi and Nasr El Din, 2005).
7. Inadequate of diversion technique: A critical factor to the success of the acidizing treatment is the proper placement of the acid. If a significant variation exists in the reservoir permeability, the acid tends to flow primarily into the highest-permeability zones, leaving less permeable zones virtually untreated. Thus, the distribution of the acid into the formation is an important consideration in the acidizing operation. Therefore, the design should include plans for acid placement (Chang et al., 2007; Hill and Rossen, 1994).
8. Incorrect acid volume: The relation between the damage and the volume of acid is direct. Increasing the volume of acid increases the etched penetration which depends on the fluid loss and reaction rates (Subero and Holder, 1996).
9. Incorrect calculations: Accurate calculations for the design parameters (such as pumping pressure and pumping rate) are very important to get successful acid design.

Model Assumptions and Considerations

AAA program is developed based on the following assumptions and considerations:

1. Fluid flow is steady-state radial flow;
2. The well type is oil well or water injector;
3. The model is single phase flow
4. The well is vertical well;
5. The movement of the fluid in the pipe and the formation is piston-like (no disturbance, cross-flow, or fingering occurs at the interface of any two fluids);

6. Reservoir type is a single reservoir;
7. The program deals with formation (sandstone , carbonate)
8. Maximum temperature is 400°F;
9. Occurrence of one type of damage; and
10. If the data of the reservoir radius, well bore radius, water viscosity, and oil formation volume factor are not available; AAA program assumes them as the following:
    - Reservoir radius (Re)= 3000 ft
    - Well bore radius (Rw)= 6 in
    - Water viscosity (μ_w)= 1 cp
    - Oil formation volume factor (Bo)= 1.01 STB/bbl

Case Studies

AAA program has been tested, validated and applied. Till now, AAA program has been used to audit and evaluate the design of eight acidizing programs. It was found that the results of AAA program are consistent with the actual performance of the acidizing operations after their implementation. AAA program successfully predicts the behavior of the acidizing operations. It also recommends the necessary preventive actions to mitigate the reasons of the failure. This work presents only the results of the application of AAA program in three acidizing operations for Well I, Well II and Well III.

Well I

This well is located in Sirte Basin in Libya. Table 8 presents the data of this well. The initial production rate of Well I is 500 bbl/d with zero water cut (Feb. 2008). In May 2010, the production rate was 410 bbl/d. After the implementation of a workover operation in May 2010; formation damage was formed around the well bore and the production rate became 120 bbl/d.The field also suffered calcium carbonate scale. Therefore, it was recommended to acidize this well.

TABLE 8 DATA OF WELL I

Well data			
Deviation	0	Tubing volume	105.1 bbl
Completion type	Steel	Casing volume below packer	28.2 bbl
Outside diameter of the completion	3.5 in	Open hole or cased hole	Cased hole
Inside diameter of the completion	2.99 in	Perforated interval	13211-13248ft
Minimum inside diameter	2.25 in	Primary cementing	No
Well bore radius	5 in	True vertical data	13605ft
Tubing end	12094 ft		
Production data			
Production rate	120bbl/d	H2S	0
Water cut	0	Bo	1.01
Damage radius	0.5 ft	Viscosity	15 cp
Does the oil contain asphaltin?			No
Does the oil contain paraffin?			No
Reservoir data			
Porosity	14%	Skin factor	1.5
Permeability	55 md	Drive mechanism	Water drive
Reservoir pressure	4800 psi	Reservoir temperature	240°F
Fracture pressure	9000 psi		
Mineralogy data			
Formation type	Dolomite	Is the cementing material carbonate?	No
Clays content	0%	Formation damage type	Calcium carbonate
Lab data and rig operation			
Emulsion	No	Sludge	No

TABLE 9 DATA OF THE ORIGINAL ACIDIZING PROGRAM FOR WELL 1

Program procedures			
Job description	Acid wash	Do you use diversion?	No
Acidizing technique	Regular	Placement technique	CT
Design steps	Pressure test - main treatment - over-flush soaking time - flow back		
Coil tube outside diameter	1.5 in	Coil tubelength	10,000ft
Treatment design			
Pressure test	5000 psi	Pickling volume	0
Main treatment additives			
Volume	3700gal	Treatment	15 % HCl
Surfactant	0.20%	Iron control	0.50%
Inhibitor	0.0%		
Viscosity	1 cp	Density	8.4 ppg
Pumping pressure	1000 psi	Pumping rate	0.6 bbl/min
Over-flush additives			
Volume	4200 gal	Treatment	KCl 2 %
Viscosity	1 cp	Density	8.45
Pumping pressure	1000 psi	Pumping rate	0.6
Soaking time and flow back			
Flow back type	Coil tube and N2	Soaking time	90 Min

Table 9 presents the data of the original acidizing program prepared to remove the formation damage. After the preparation of the acidizing program; AAA program was used to audit it. Table 10 presents the output data of AAA program. It is clear from Tables 9 and 10 that the pumping pressure and pumping rate of the acid in the proposed program are reasonable. However, Table 10 identifies four inaccurate design parameters and proposes four corresponding recommendations as follows:

TABLE 10 OUTPUT DATA OF AAA PROGRAM FOR WELL 1

Job Identification
Company Name:E
Field/Well Name:Site Basin 7
Job Description
Acid wash is not suitable, Matrix acidizing should be used
Design Steps
The pickling step should be done for coiled tubing string
Placement Technique
The coiled Tubing sting should be taller than TD
Pickling
Preflush
Main Treatment
Acid inhibitor aid should be added
The max pumping rate is 3.6 bbl/min
The max pumping pressure:2571 psi
The minimum pumping rate:0.24 bbl/min
Over flush
Soaking time & Flow back

1. The original acidizing program indicates that the acidizing operation shall be conducted with acid wash. However, AAA program is recommended to use matrix acidizing because the damage radius in the formation is about 0.5 ft. It should be mentioned that the comparison between the damage radius (0.5 ft as shown in Table 8) against the screening criteria of the production data (Table 4) led the program to provide this recommendation.

2. The proposed acidizing program does not include the pickling step. AAA program is recommended to include pickling step in the acidizing program to avoid the movement of rust, scale, wax, and pipe dope into the formation and cause severe damage. It is clear that the value of the pickling volume in Table 9 (zero) led the program to provide this recommendation. Cancelation of any step of the acidizing sequence might lead to a failure in the acidizing program.5

3. The coiled tubing string in the proposed acidizing program is shorter than the total depth of the well. AAA program highlights this issue and indicates that the coiled tubing string should be taller than the total depth of the well. It should be stated that the comparison between the total depth of the well (13,605 ft) and the length of the CT (10,000 ft) in Tables 8 and 9 against the screening criteria of the well data (Table 2) led the program to provide this recommendation.

4. The proposed acidizing program does not include acid inhibitor aid. AAA program recommends to use acid inhibitor aid (as the temperature is high) to avoid the corrosion of the casing and tubing. It should be mentioned that the HCl is very corrosive at high

temperatures (Don Hill et al., 2000). The comparison between the reservoir temperature (240°F as shown in Table 8) and the value of the inhibitor in Table 9 (zero) against the screening criteria of the reservoir data (Table 3) led the program to provide this recommendation.

After the implementation of the acidizing program with the recommendations of AAA program; the acidizing operation was successfully performed. The production rate of the well increased from 120 bbl/d to 485 bbl/d and the well head pressure increased from 25 to 90 psi as shown in Table 11.

Well II

This well located in Sirte Basin in Libya was drilled in 2007 and started its production with a rate of 1300 bb/d and zero water cut. Table 12 presents the data of this well. In Jan 2009, workover operation was performed to repair the casing leakage. The production rate in Jan 2009 declined from 1180 to 700 bbl/d with zero water cut. The formation was damaged due to the presence of calcium carbonate in the workover fluid. Therefore, it was recommended to acidize this well.

Table 13 presents the data of the proposed acidizing program. After the preparation of the acidizing program, AAA program was used to audit it. Table 14 presents the output data of AAA program. AAA program confirms the adequacy of the proposed acidizing program without any recommendations. Table 14 confirms also that the pumping pressure and pumping rate of the acid in the proposed program (Table 13) are reasonable.

After the implementation of the acidizing program, it was found that the results of AAA program are consistent with the actual behavior of the formation and the job is successful as shown in Table 15. The production rate increased after the acidizing operation from 700 bbl/d to 1135 bbl/d. Moreover, the well head pressure increased from 80 psi to 230 psi.

TABLE 11 WELL HEAD PRESSURE AND PRODUCTION RATE OF WELL I

Parameter	Initial conditions (Feb.2008)	Before the damage before the workover (May 2010)	After the workover before the acidizing (May 2010)	After the acidizing (June 2010)
Production rate,* bbl/day	500	410	120	485
Well head pressure, psi	95	80	25	90

* Note: water cut is zero

TABLE 12 DATA OF WELL II

Well data			
Deviation	0	Tubing volume	78 bbl
Completion type	Steel	Casing volume below packer	7 bbl
Outside diameter of the completion	3.5 in	Open hole or cased hole	Cased hole
Inside diameter of the completion	2.99in	Perforated interval	8910 - 8970ft
Minimum inside diameter	2.25 in	Primary cementing	Normal
Well bore radius	8.5in	True vertical depth	9000ft
Tubing end	8000ft		
Production data			
Production rate	700	H2S	0
Water cut	0	Bo	1.01
Damage radius	2 ft	Viscosity	15 cp
Does the oil contain paraffin?			No
Does the oil contain asphaltin			No
Reservoir data			
Porosity	15%	Skin factor	3.6
Permeability	25md	Drive mechanism	Water Drive
Reservoir temperature	320°F	Fracture pressure	6100psi
Reservoir pressure	3700psi		
Mineralogy data			
Formation type	Carbonate	Is the cementing material carbonate?	No
Clays content	0%	Formation damage type	Calcium carbonate
Lab data and rig operation			
Emulsion	No	Sludge	No

TABLE 13 DATA OF THE ORIGINAL ACIDIZING PROGRAM FOR WELL II

Program procedures					
Job description	Matrix	Do you use diversion?		Yes	
Acidizing technique	Retarder combined	Type of diversion		Foam	
Design Steps	Pressure test - pickling - main treatment - over-flush soaking time - flow back				
Placement technique	Coil tube	Coil tube outside diameter	1.5in	Coil tube length	15,000 ft
Treatment design					
Pressure test	4500psi	Pickling volume		800 gal	
Pickling additives					
15 % HCl	800 gal	Surfactant		0.20%	
Inhibitor	0.80%				
Density	8.35ppg	Displaced by		Water	
Main Treatment additives					
Volume	4500gal	Treatment		Combined acid	
Mutual solvent	5%	Iron control		0.50%	
Inhibitor	0.50%	Inhibitor aid		0.50%	
Viscosity	1cp	Density		8.33 ppg	
Pumping pressure	1000 psi	Pumping treatment		0.5 bbl/min	
Over flush additives					
Volume	1600 gal	Treatment		KCl 2 %	
Viscosity	1 cp	Density		8.45 ppg	
Pumping pressure	1000 psi	Pumping rate		1 bbl/min	
Soaking time and flow back					
Flow back type	Coil tube and N2	Soaking time		60 Min	

TABLE 14 OUTPUT DATA OF AAA PROGRAM FOR WELL II

Job Identification
Company Name:A
Field/Well Name:Sirte Basin 3
Job Description
Design Steps
Placement Technique
Pickling
Preflush
Main Treatment
The max pumping rate is:1.2 bbl/min
The max pumping pressure:1589 psi
The minimum pumping rate:0.3 bbl/min
Over flush
Soaking time & Flow back

TABLE 15 WELLHEAD PRESSURE AND PRODUCTION RATE OF WELL II

Parameter	Initial conditions (Sep. 2007)	Before the damage before the workover (Jan 2009)	After the workover before the acidizing (Jan 2009)	After the acidizing (Jan 2009)
Production rate,* bbl/day	1300	1180	700	1135
Well head pressure, psi	260	190	80	230

* Note: water cut is zero

Well III

This well was drilled and completed in 1981 at the Sirte Basin in Libya. After excessive production with ESP; the water cut increased to 95%. Then, it was converted into a water injection well in 2006. The injection rate started with 3000 bbl/day. Then, it declined to 2000 bbl/day in February 2010. The production logging tools (PLT) was executed to evaluate the injection rate profile for the perforated intervals. The PLT showed that the upper interval (from 5615 to 5642 ft) received around 75% of the total injection rate; while the lower interval (from 5672 to 5688 ft)received the rest. Therefore, the operating company took a decision to stimulate the lower zone.

Tables 16 and 17 present the data of the well and the data of the proposed acidizing program, respectively. The main idea in the proposed acidizing program is the usage of bull heading placement technique with in-situ gelled acid as a chemical diversion to direct the acid into the low permeable zone (damaged zone). In the damaged zone, the regular acid is used with its additives to remove the formation damage and create new wormholes.

After the preparation of the acidizing program, AAA Program was used to audit it. Table 18 presents the output data of AAA program, which confirms the adequacy of the proposed acidizing program without any recommendations. Table 18 indicates also that the pumping pressure and pumping rate of the acid in the proposed program (Table 17) are reasonable.

After the implementation of the acidizing program, it was found that the results of AAA program are consistent with the actual behavior of the formation and the Job is successful. The injection rate increased after the acidizing job from 2000 bbl/d to 2920bbl/d. The acidizing job increased the injection rate to almost the normal injection rate. Moreover, the well head pressure decreased from 370 psi to 110 psi. The PLT which was conducted after the acidizing job indicated that the injection profile came back to its normal behaviour.

TABLE 16 DATA OF WELL III

Well data			
Deviation	0	Tubing volume	27.4 bbl
Completion type	Steel	Casing volume below packer	2.7 bbl
Outside diameter of the completion	3.5 in	Open hole or cased hole	Cased hole
Inside diameter of the completion	2.99 in	Perforated interval	5672-5688ft
Minimum inside diameter	2.19 in	Primary cementing	Normal
Well bore radius	6.276 in	True vertical depth	5700 ft
The depth of Tubing end	5300 ft		
Production data			
Injection rate	2000 bbl/day	H2S	0
Damage radius	1ft	Viscosity	1 cp
Does the oil contain paraffin?			No
Does the oil contain asphaltin			No
Reservoir data			
Porosity	19%	Skin factor	6
Permeability	40 md	Reservoir pressure	1950 psi
Reservoir temperature	170°F	Fracture pressure	4900 psi
Mineralogy data			
Formation type	Limestone	Is the cementing material carbonate?	No
Clays content	0 %	Formation damage type	Inorganic scale
Lab data and rig operation			
Emulsion	No	Sludge	No

TABLE 17 DATA OF THE ORIGINAL ACIDIZING PROGRAM FOR WELL III

Program procedures			
Job description	Matrix	Do you use diversion?	Yes
Acidizing technique	Regular	Type of diversion	In-situ gel acid
Design steps	Pressure test - Pickling - Pre-flush - Main treatment - Over-flush - Soaking time		
Treatment design			
Pressure test	3000 psi	Pickling volume	500 gal
Pickling additives			
15 % HCl	500 gal	Surfactant	0.20%
Inhibitor	0.40%	Iron control	0.60%
Density	8.3 ppg		
Pre-flush additives			
Volume	400 gal	Treatment	2% KCl
Viscosity	1 cp.	Density	8.45 ppg
Pumping pressure	1000 psi	Pumping rate	0.4bbl / min
Main treatment additives			
Volume	1250 gal.	Treatment	15% HCl
Iron control	0.60%	Surfactant	0.30%
Mutual solvent	7%	Inhibitor	0.40%
Viscosity	1 cp.	Density	8.3 ppg
Pumping pressure	1000psi	Pumping rate	0.4 bbl/min.
Over flush additives			
Volume	3200 gal	Treatment	KCl 2 %
Viscosity	1cp	Density	8.45ppg
Pumping pressure	1000 psi	Pumping rate	0.4 bbl/min
Soaking time and flow back			
Flow back type	No	Soaking time	60 Min

TABLE 18 OUTPUT DATA OF AAA PROGRAM FOR WELL III

Job Identification
Company Name:D
Field/Well Name:Siite Basin 1
Job Description
Design Steps
Placement Technique
Pickling
Preflush
The max pumping rate is:0.5 bbl/min
The max pumping pressure:1900psi
Main Treatment
The max pumping rate is:0.5 bbl/min
The max pumping pressure:1944 psi
The minimum pumping rate:0.08 bbl/min
Over flush
Soaking time & Flow back

Conclusions

This paper has presented a new developed computer program (Acidizing Auditor Advisor program: AAA program) that can be used as an auditor and advisor to evaluate the design of the acidizing operation before its implementation. The developed program can be also used to recommend proper design conditions to achieve successful acidizing operations. AAA program has been tested, validated and applied.

Three case studies have been presented in this work. It was found that the results of AAA program are consistent with the performance of the actual acidizing operations, the behavior of the acidizing operations were successfully predicted and the necessary preventive actions were recommended to mitigate the reasons of any failure.

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