PETROVIETNAM JOURNAL
Volume 6/2019, p. 41 - 47
ISSN-0866-854X

Characterisation of acid treatment for damaged zone in fractured granitic basement of Bach Ho field

Nguyen Quoc Dung, Pham Trung Son, Nguyen Van Trung, Nguyen Van Nga
Vietsovpetro Joint Venture
Email: dungnq.rd@vietsov.com.vn

Summary

Bach Ho is the largest reservoir in the continental shelf of Vietnam. This field consists of numerous oil pay zones, from Lower Miocene, Upper Oligocene, Lower Oligocene to Cenozoic fractured basement, which is known for a unique oil zone with nearly 2,000m in thickness. This oil zone features a large number of naturally flowing wells with production rate of approximately 1,000 tons per day, contributing to over 90% of total production.

The oil pay zone in the fractured granitic basement is considered unconventional with extremely high degree of heterogeneity, anisotropy, and permeability. This requires more challenging production methods than those applied for conventional pay zones around the world. To achieve current optimal treatment methods, Vietsovpetro has been researching, selecting, and applying various acid treatment methods for damaged zones in this complicated basement. Nowadays, these treatment methods are successfully performed in most reservoirs in the continental shelf of Vietnam.

The success of research and application of acid treatment for pay zones in Bach Ho fractured granitic basement has made significant scientific and technological contribution not only to Vietnam but also to the South East region and the world. This paper will present the acid treatment methods applied for Bach Ho fractured basement reservoir and their techniques to optimise the production.

Key words: Near bottomhole, damaged, acid treatment, high temperature reservoir, mud acid, acid salt, acid-in-oil emulsion, non-acidic, acid-in-oil-gas emulsion, fractured basement, Bach Ho field.

1. Introduction

The basement reservoir at Bach Ho field is a reservoir granite volume of cavities and pores, with multiple cracks and micro-cracks acting as oil-filled channels. The cracks and micro-cracks are 0.3 - 3mm in size; the porosity ranges from 3 to 5%; the permeability greatly varies from 0.004 to 464D with an average of 0.135D. The reservoir temperature is relatively high, ranging from 130 to 155°C. The reservoir pressure measured at 3,650m ranges from 200 to 320atm. Results from minerology tests indicate that the basement rocks of Bach Ho field are composed of mostly granite, granodiorite, quartz - monzodiorite, diorite, and quartz - diorite.

Granite rocks at Bach Ho field are highly fractured and porous (mostly deal to cracks and micro-cracks). The dominated secondary minerals are zeolite and calcite.

Date of receipt: 16/4/2018. Date of review and editing: 16/4 - 1/6/2018.
Date of approval: 3/6/2019.

Granodiorite rocks features breccia form with debris of various shapes, colours, and sizes; this variety is deal to carbonitisation and zeolitisation processes. Cracks inside rocks also occur in various shapes; they are mostly filled with zeolite, carbonate, or chlorite. Their width can range from several millimetres to several centimetres.

In general, the basement rocks at Bach Ho field include:

- Neutral rocks (58 - 64% SiO_2) include diorite quartz biotite and diorite quartz amphibole - biotite presenting at the North East, North West, North and Centre Blocks;

- Weakly acidic rocks (64 - 68% SiO_2) at Jurassic Age include adamellite, granodiorite, granodiorite biotite, tonalite, monzonite, quartz monzonite and biotite - amphibole in the drilling wells located in the North West and North Blocks.

- Acidic rocks (68 - 74% SiO_2) before Late Cretaceous Age are mainly granite biotite in the drilling wells located in all of the blocks.

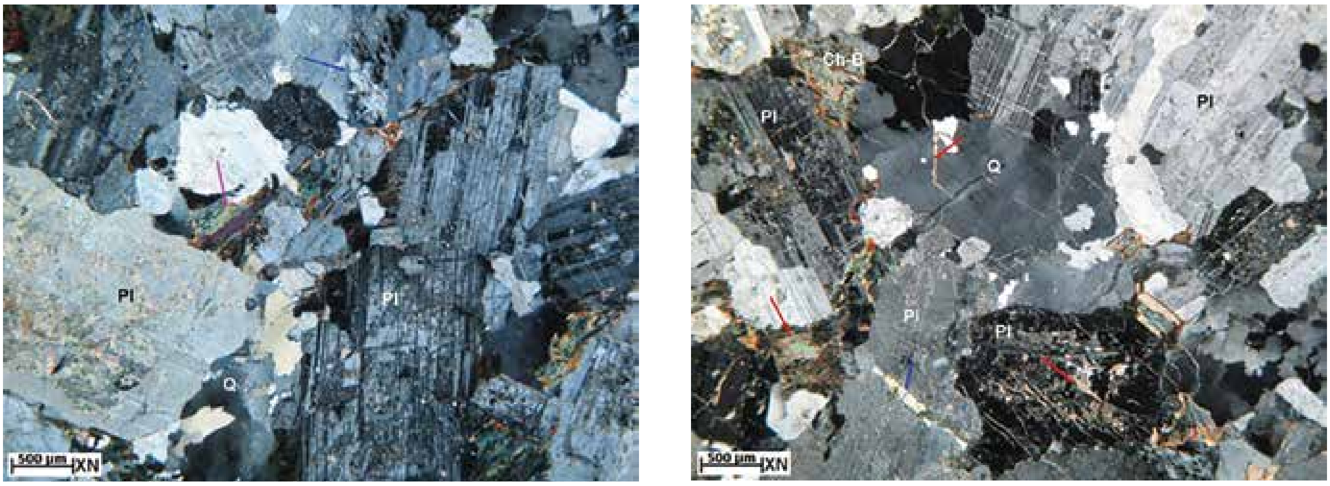

Figure 1. Minerology of gradiorite from XRD Red arrows: calcite, blue arrows: zeolite, pink arrow: chlorite.

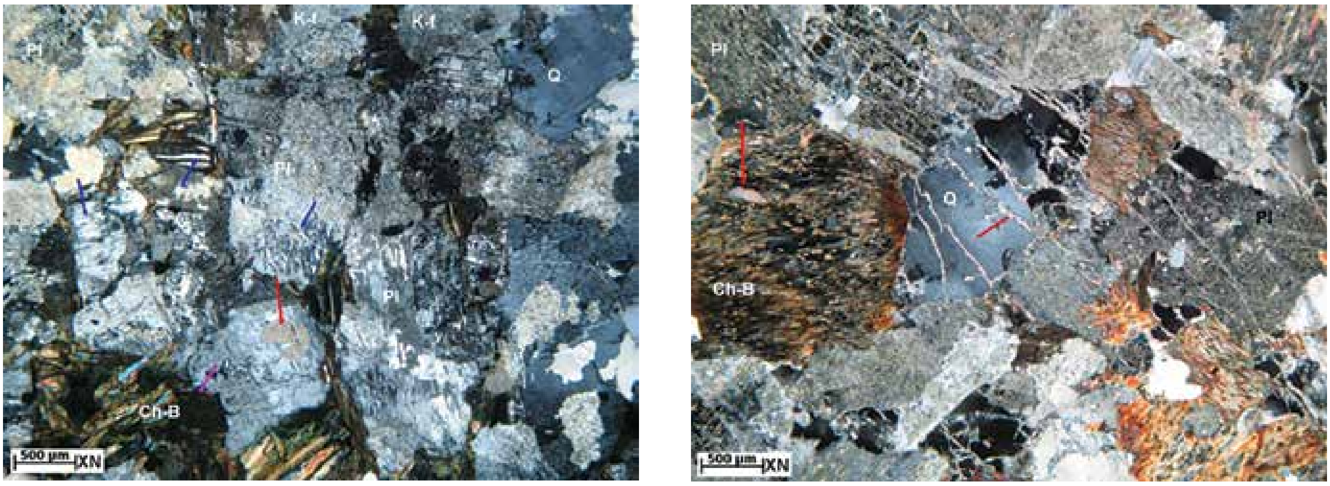

Figure 2. Minerology of gradiorite from XRD Red arrows: calcite, blue arrows: zeolite, pink arrow: chlorite.

Lithologically, the basement rocks at Bach Ho field compose of granodiorite and granodiorite biotite cataclasis. They are light grey in colour, medium in size, poorly sorted, medium to highly fractured, and highly compacted. The minerals presented in the rocks include: plagioclase (35 - 54%), potassium feldspar (mainly microcline: 1 - 10%), and orthoclase (12 - 24%), quartz (13 - 27%), and biotite (13 - 21%).

2. Concept and causes of damage near bottomhole

2.1. Concept of damage near bottomhole

Near bottomhole zone is the reservoir area surrounding the wellbore which plays a crucial role in the pressure drop under the effects of formation damage factors (Figure 3). About 30 - 50% of pressure reduction occurs in this zone. The damaged zone is typically 0.9 - 1.5m (3 - 5ft) in radius. However, the most significant damaged zone, which is mainly responsible for the pressure drop, is no more than several inches (about 5 - 9cm) in radius. For drilling wells with casing diameter of 140mm and reservoir homogeneous permeability near the wells, the resistance force at the distance of 5cm from the wellbore is 8 times greater than that at the distance of 1m from the wellbore.

2.2. Causes of damaged zone

For a typical reservoir of sedimentary rocks, there are numerous causes of formation damage: damage resulted during drilling, production, well treatment, or workover process, etc. Based on the components of formation damage, 2 types of formation damage causes are distinguished: inorganic deposition and organic deposition. In reality, there is also the case where mixed organic and inorganic deposition occurs.

For the wells in the basement reservoir, formation damage occurs mainly during drilling and completion processes. The partial and total lost circulation problems during the drilling process can be solved by lost circulation

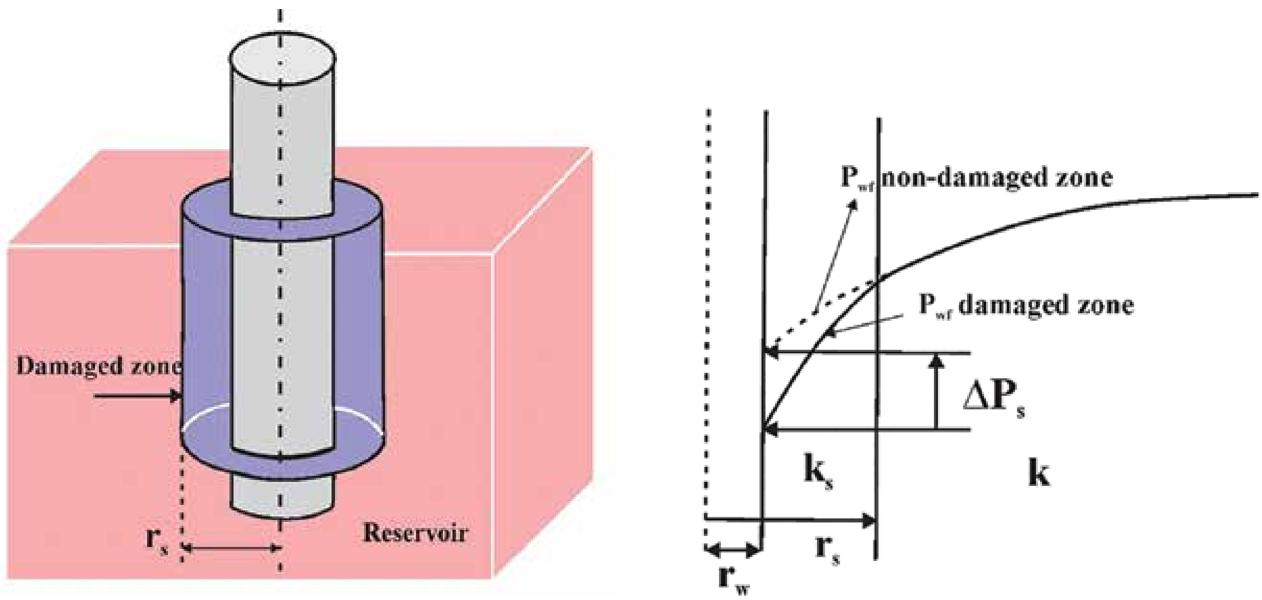

Figure 3. *Damaged zone and the pressure drop occurring in the damaged zone.*

Table 1. *Composition of different LCM solutions [1]*

No.	Composition of LCM solutions
1	Technical water + Bentonite API + Xanvis + Shell (d = 1 - 5mm) + $CaCO_3$ (F) + $CaCO_3$ (d < 0.3mm)
2	Technical water + Bentonite API + Xanvis + Shell (d = 1 - 5mm) + $CaCO_3$ (F) + $CaCO_3$ (d = 0.3 - 0.9mm)
3	Technical water + Bentonite API + Xanvis + Shell OBK (d < 1.5mm) + Shell (d = 1 - 5mm)
4	Technical water + Bentonite API + CMCLV + DUOVIS + $CaCO_3$ (F) + Glass bubble 3M (d ≤ 100µm) + Glass bubble 3M (d ≤ 200µm)
5	Technical water + Bentonite API + Xanvis + $CaCO_3$ (d < 0.9mm) + $CaCO_3$ (d < 1.25mm) + Shell (d = 1 - 5mm) + Nut plug (M) + Nut plug (F) + Kiwik seal (M) + KR22
6	Technical water + Bentonite API + Xanvis + OBK (d < 0.9mm) + OBK (d < 1.25mm) + Shell (d = 1 - 5mm) + Nut plug (M) + Nut plug (F) + Kiwik seal (M) + KR22

materials (LCM). The amount of LCM applied depends on the degree of the lost circulation. These LCM are stuffed into the channels and fractures, resulting in formation damage and thus preventing the fluid from flowing to the wellbore.

The LCM applied for the basement rocks are grains, fibres, or flakes. Researches on characterisation of fractures in the basement reservoir at Bach Ho field and practical results of LCM suggest that the optimal size of LCM grains for highly fractured formation are medium (74 - 200µm) and fine (≤ 74µm). The results also indicate that multiple sized LCM are more effectively filled into fractures than single sized LCM. Therefore, LCM with multiple sizes are used to solve lost circulation problems in the fractured basement reservoir.

To protect the reservoir, LCMs are preferably soluble in acid. Lost circulation experiments signify that the combination of different types of LCM (grain, fibre, and flake) in the solution also improves the effectiveness of the fracture filling. Hence, the LCM solution applied for the fractured basement reservoir consists of multiple types of LCM.

The applied LCMs include:

- Grain type: Scotchlite 3M Scotchlite (Scotchlite glass bubble 3M - HGS); $CaCO_3$ grains;

- Fibre type: Kiwik seal. Kiwik seal is a synthetic LCM fibre, proved to be highly effective in lost circulation solution;

- Flake type: $CaCO_3$ artificial flakes. They are highly soluble in acid but are expensive. Shells, which are abundant in Vung Tau sea, are more economical and more mechanically durable.

In addition to the mentioned types, nut plug type is widely applied around the world.

It is noticed that a large amount of secondary minerals present inside the fractures of the rocks such as calcite, zeolite, chlorite, and clays (Figures 1 and 2). These minerals reduce the permeability. As a result, the actual

***Table 2.** The quality of different treatment methods for basement reservoir - Bach Ho field [2]*

Target area	Acid treatment methods	Production wells	
		Number of treated wells	Successful percentage (%)
Basement reservoir	Acid salt (HCl)	6	0
	Mud acid	90	78
	Acid salt + mud acid	6	100
	Acid-in-oil emulsion (clay based acid)	75	87
	Acid-in-oil-gas emulsion	6	83
	Acid + Chemical of DMC	38	63
	Acid-in-oil emulsion (acid based salt)	3	67
	Foam acid	3	67
	Non-acid	2	100
	Total	**229**	**72**

flow rates of the wells are significantly lower than the flow rates expected from good characteristics of the basement reservoir.

Therefore, the acid treatment job in the fractured basement rocks is considered successful when LCMs and the remaining secondary minerals within cracks and micro cracks are effectively dissolved.

3. Synthesis of acid treatment methods for damage near bottomhole applied for Bach Ho fractured granitic basement reservoir

Vietsovpetro has conducted researches, selected and applied numerous acid treatment methods for damaged zone in the fractured basement reservoir. Thus far, many treatment methods have yielded good results and have been applied for other oil and gas reservoirs owned by Vietsovpetro.

By the end of 2017, the production wells in the basement reservoir at Bach Ho field were treated 229 times, with the successful percentage of 72%.

4. Chemicals used in acid treatment for damaged zone

The main acid solutions applied for acid treatment are acid salt and clay acid solutions. The acid salt solution contains hydrochloric acid (HCl) and acetic acid (CH_3COOH); the mud acid solution contains hydrofluoric acid (HF), HCl, and CH_3COOH.

- HCl: dissolve calcite components and inorganic salt precipitation, dissolve partial clay components of secondary minerals causing formation damage. For clay acid, excess HCl prevents phenomena such as gel accumulation from iron compounds; precipitation of CaF_2 and MgF_2; and gel accumulation from $Si(OH)_2$. Technical HCl has the concentration of 28 - 32%.

- HF in the clay acid solution is highly hazardous and highly noxious (group III). Technical HF concentration is maintained below 30%. HF plays the main role of dissolving clay minerals, quartz minerals, and aluminosilicate in reservoir rocks or damaged surface and subsurface equipment.

- CH_3COOH: balance the pH of acid solution (≤ 2) to prevent the gel accumulation of iron hydroxide, aluminium hydroxide, and other metal ions. At the concentration > 4%, CH_3COOH helps reduce reaction rate, thus increase the affected depth.

In addition to those main chemicals, corrosion control chemicals, surfactants, and stabilisers are included in the acid salt and clay acid solutions. Corrosion control chemicals help reduce the corrosion effects of these acid solutions on wellbore equipment. Surfactants help lower the surface tension on the boundaries of fluid phases, distribute and extract solid from the reaction volume, prevent the precipitation of gudron (tar), reduce the permeability prevention effects, and prevent the precipitation of emulsion. Stabilisers help stabilise clay minerals, prevent the precipitation of iron and aluminium hydroxide, etc., and prevent the creation of hydroxide gel.

5. Acid treatment technology applied for fractured basement reservoir - Bach Ho field

As mentioned in Part 1, due to the unique characteristics of the geology of the reservoir rocks, the acid treatment technology applied for the basement reservoir faces multiple challenges:

- Great thickness of the pay zone (over 2,000m) which creates difficulties in controlling the acid flow into the reservoir.

- High reservoir temperature (130 - 155°C) which results in high reaction rate, thus shortens the affected depth.

- In addition, high reservoir temperature destabilises clay minerals and results in gel accumulation, which corrodes the wellbore equipment.

Therefore, corrosion control chemicals are added to minimise the corrosion rate under high reservoir temperature conditions.

The successful acid treatment methods applied for the basement reservoir are required to solve those problems (Table 2):

- Treatment methods using clay acid + acid salt;
- Treatment methods using non-acid solution to create acid solution at bottomhole;
- Acid-in-oil emulsion (clay-based acid);
- Acid-in-oil-gas emulsion;
- Treatment methods using clay acid.

5.1. Treatment method using combination of acid salt and mud acid solutions

Acid salt solutions are mainly applied for reservoir rocks with high percentage of $CaCO_3$ and $CaMg(CO_3)_2$. For granite reservoir, a combination of HF, HCl solutions and additives is used. HF mainly reacts with SiO_2 (silicic oxide) components and $H_4Al_2Si_2O_9$ (kaolinite).

Mud acid solution is used for reservoir rock with calcite percentage < 0.5%. If this acid reacts with carbonate or dolomite, the products are undissolved salts:

$$2HF + Ca^{2+} = CaF_2 + 2H^+$$

For reservoir rocks with clay, it is important to control the concentration of each type of acid in the acid solution that can affect clay heave, resulting in permeability reduction. The rate of reaction between soluble clay and HF is significantly slow. Therefore, the amount of HF needs to be sufficient for the reaction; in addition, CH_3COOH is required to increase the affected time of the solution to the rocks.

To eliminate the salt produced: CaF_2 and MgF_2. The acid salt treatment is conducted prior to the main acid treatment as reservoir rocks contain a great percentage of Ca and Mg.

Figure 4 illustrates a typical schema for treatment method using combination of acid salt and mud acid.

5.2. Acid treatment methods using non-acid solution to create acid solution at the bottomhole

The basis of this method is to treat the damaged zone by acid solution created at the bottomhole by pumping non-acidic components into the wellbore. This technique is called non-acid treatment method [3].

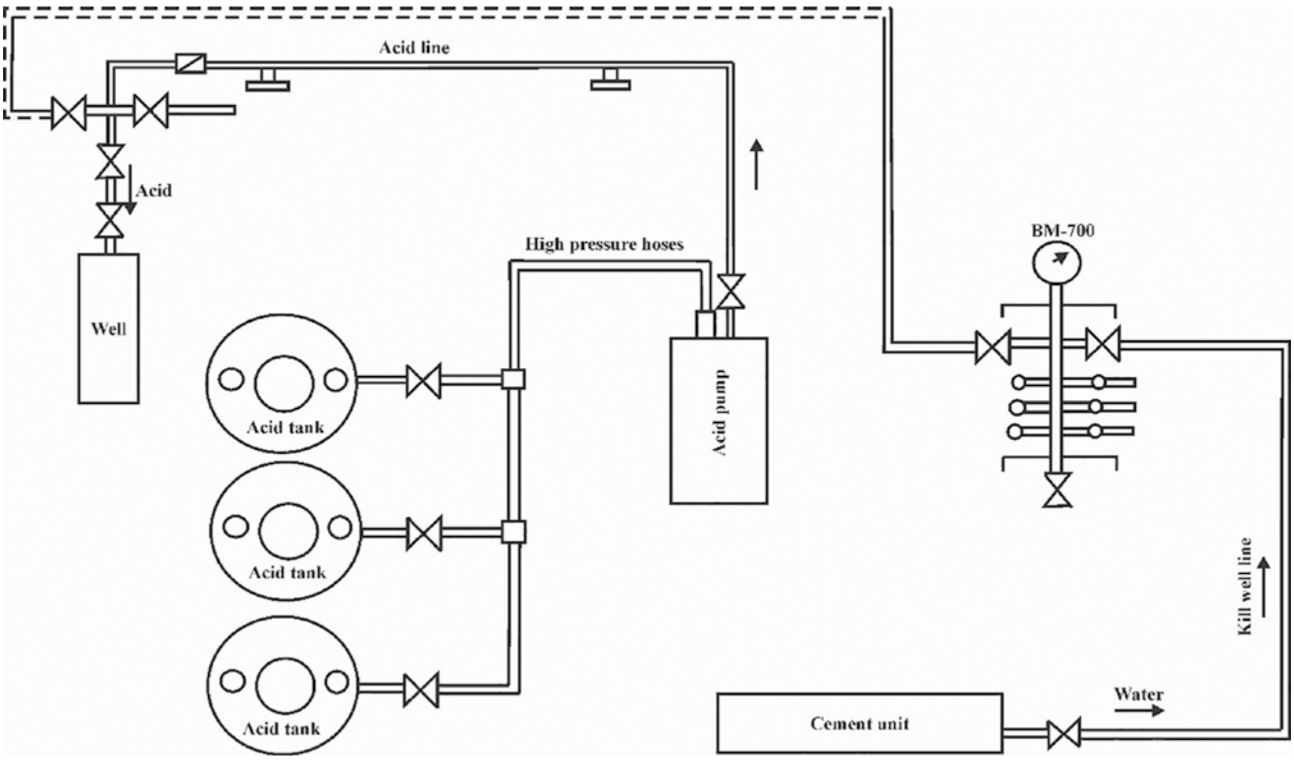

Figure 4. *Schema of acid treatment for damaged zone - Clay acid + acid salt method [2].*

Acid is created in the formation when HBF_4 and water are pumped to the damaged zone. The acid product of the reactions is HF:

$$HBF_4 + H_2O = HBF_3(OH) + HF \quad (1)$$

$$HBF_3(OH) + H_2O = HBF_2(OH)_2 + HF \quad (2)$$

In a particular time, only a limited amount of HF is created in the solution. The solubility of HBF_4 is relatively high (8% HBF_4 is equivalent to 2% HF). Under reservoir conditions, this acid duo acts similarly to the HF/HCl duo (with the concentration of HF below 1%).

Compared to a typical HF/HCl duo, the acid duo produced from HBF_4 and H_2O reaction has many advantages: lower rate of corrosion of borehole equipment and casing, good acid concentration maintenance, and prevention of precipitation.

Figure 5 illustrates a typical schema for the non-acid treatment method.

5.3. Acid treatment methods using acid-in-oil emulsion (mud-based acid)

Acid-in-oil emulsion includes two phases: acid and hydrocarbon (which can be either crude oil or diesel). Acid is the dispersed phase; crude oil is the dispersion medium.

When the area of surface boundaries between acid in the acid-in-oil emulsion and the reservoir rocks decreases, the solution will invade deeper into the formation compared to normal acid solution, the rate of metal corrosion by acid solution will also decrease.

Depending on the fluid ratio, there are different types of acid-in-oil emulsions. Typically, there are 60 - 70% acid and 40 - 30% crude oil. The acid solution is normally clay acid.

Depending on the geologic - technical condition of the wells, suitable schema for the treatment is selected (Figure 6).

5.4. Acid treatment methods using acid-in-oil-gas emulsion

Bach Ho field is a high temperature reservoir. When the area of surface boundaries between acid in the acid-in-oil emulsion and the reservoir rocks decreases, the solution will invade deeper into the formation as compared to normal acid solution, and the rate of metal corrosion by acid solution will also decrease. The gas phase in acid-in-oil-gas emulsion supports the swab process after the treatment.

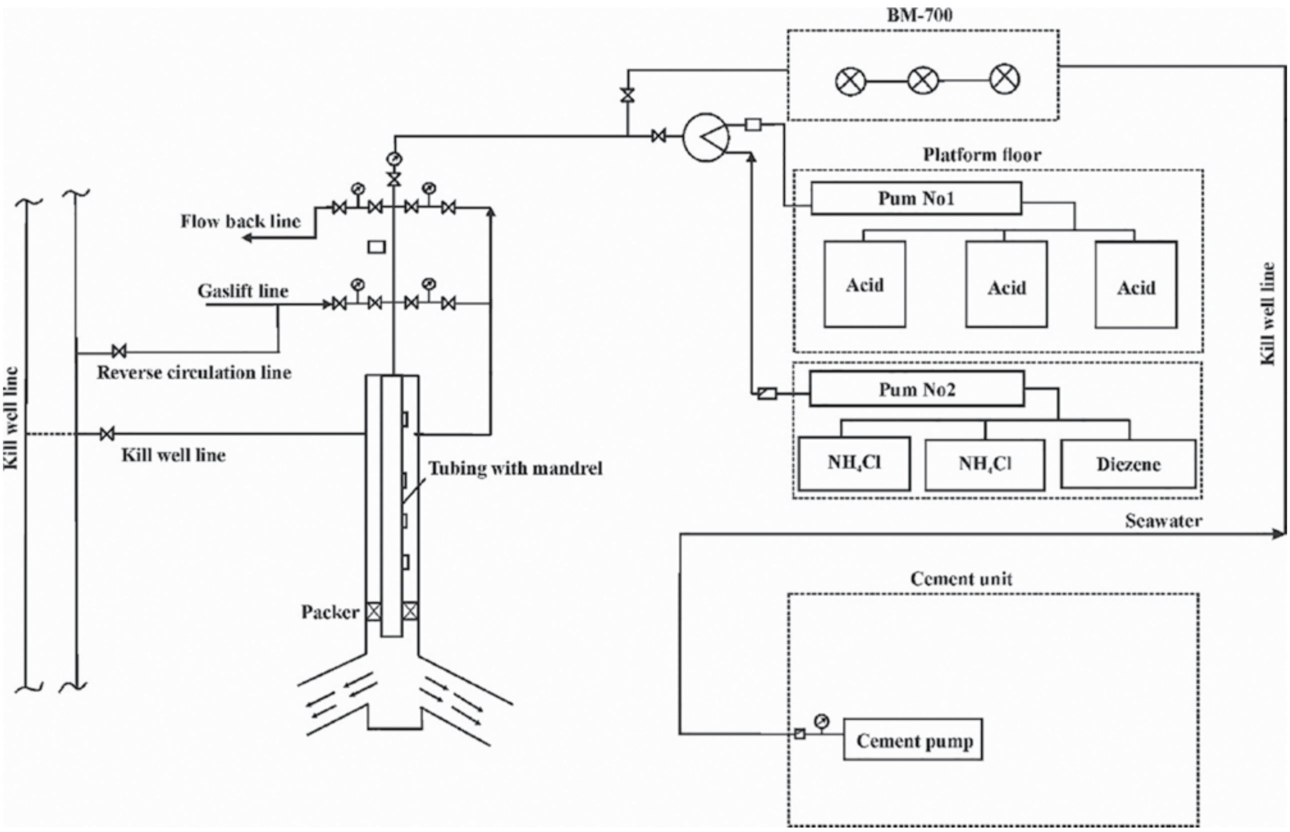

Figure 5. *Schema of acid treatment for damaged zone - non-acid solution method [3]*

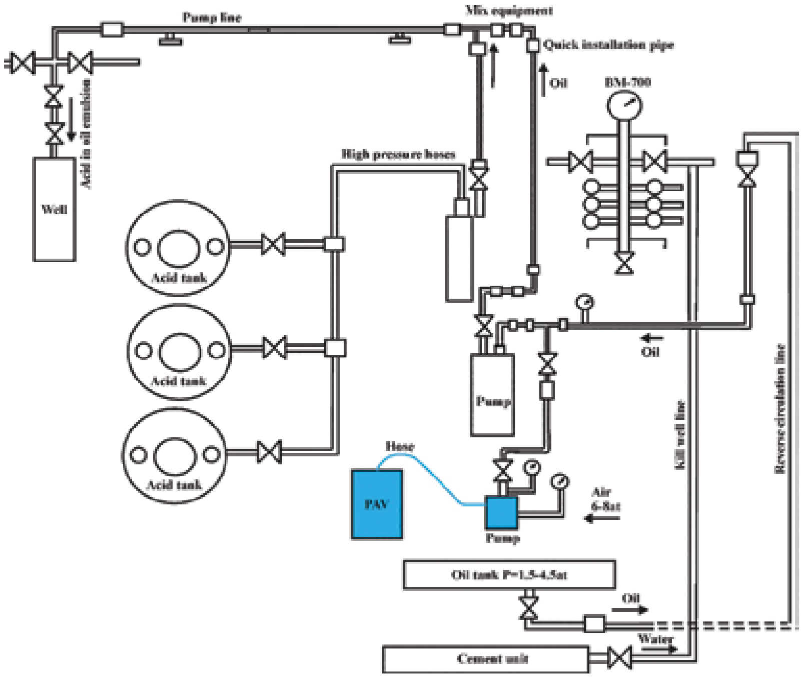

Figure 6. *Schema of acid treatment for damaged zone - acid-in-oil emulsion methods on fixed platform [2].*

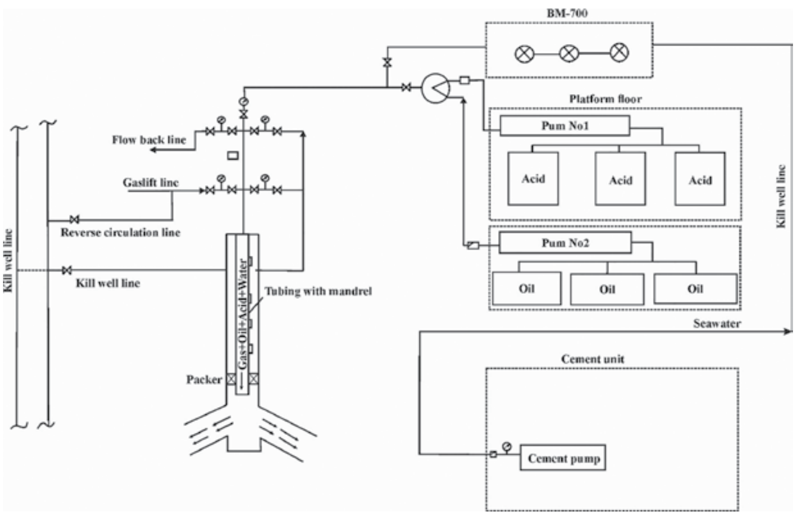

Figure 7. *Schema of acid treatment for damaged zone - acid-in-oil-gas emulsion method [4].*

The acid-in-oil-gas emulsion treatment method was proposed by Vietsovpetro experts to target the production wells in the basement reservoir. This method is performed by simultaneously or continuously pumping each component of the emulsion (acid, oil, diesel or separated oil, and gas) into the wellbore (Figure 7).

The ratio of the components and their order of pumping are selected to achieve the optimal gas solubility in the emulsion solution and maximise the travel distance of the emulsion solution into the formation. For the wells under low reservoir pressure, after the acid treatment, the damaged zone is strongly swabbed; the impurities and reaction products will follow the flow to the wellbore.

6. Conclusion

On the basis of researches and practical application of formation damage treatment, a number of treatment methods has been selected and recommended: treatment methods using combination of acid salt and clay acid solutions, acid-in-oil emulsion (clay-based acid), acid-in-oil-gas emulsion, and non-acid solution. These treatment methods are applied to the basement of other reservoirs with similar characteristics located in the continental shelf of the South of Vietnam and yield great economic results.

The success of selecting optimal acid treatment methods for the fractured basement reservoir with high temperature as well as unique geological and mineralogical features contribute greatly to the big picture of the oil and gas production for the reservoirs in their late time in Vietnam and around the world.

References

1. Hoang Hong Linh, Tran Xuan Dao. *Research the relationship between lost circulation and fractured characteristics of Bach Ho basement for selecting the suitable LCM pill recipes to fight against lost circulation and protect the reservoir*. Science and Technics Publishing House. 2018.

2. Từ Thành Nghĩa, Nguyễn Thúc Kháng, Lê Việt Hải, Dương Danh Lam, Nguyễn Quốc Dũng, Nguyễn Văn Trung, Phan Đức Tuấn. *Công nghệ xử lý vùng cận đáy giếng ở thềm lục địa Nam Việt Nam*. Nhà xuất bản Đại học Quốc gia Việt Nam. 2016.

3. Dương Danh Lam, Lê Việt Hải, Nguyễn Quốc Dũng, nnk. *Phương pháp xử lý axit bằng thành phần non-acid để tạo axit ở đáy giếng*. Giải pháp sáng kiến sáng chế. 2012.

4. Dương Danh Lam, Nguyễn Thúc Kháng, nnk. *Phương pháp xử lý vùng cận đáy giếng bằng nhũ tương khí-dầu-axit trong các giếng mỏ Bạch Hổ có áp suất cao*. Vietsovpetro. 13 July, 1997.