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Comparative analysis of matrix-retarded acidizing methods for tight carbonate reservoirs: Gelled acid, micro-emulsified acid, and foamed acid

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Introduction

The matrix acidizing method has been widely employed in the petroleum industry to increase the output of oil and gas from reservoirs that have low permeability and are experiencing formation degradation as a result of drilling, stimulation, and completion activity (Mohsin et al., 2019). It is a method of dissolving carbonate reservoirs (calcite or dolomite) by injection of HCl, which reacts with minerals in the rock formation to increase permeability and production close to the wellbore (Buijse and Domelen, 1998). The new 'wormhole' channels are created by the introduction of the treatment fluid at a downhole injection pressure just below the fracturing pressure to bypass the damaged zone near the wellbore (Amro, 2002; Kiani et al., 2021). The wormholes are formed from the reaction of HCl with the $CaCO_3$ and $CaMg(CO_3)_2$ minerals in the matrix, which avoids the possibility of formation damage (Chang et al., 2007).

Importance of matrix acidizing for tight carbonate reservoirs

In carbonate formations, the purpose of matrix acidizing is primarily to restore and enhance the formation's productivity; but, it also reduces near-wellbore damage and establishes novel hydrocarbon flow channels (wormholes) (Ibrahim et al., 2020). By obstructing the path that the acid normally takes, these agents redirect it to the less permeable, untreated zones as shown in Figure 1 (Ghommem et al., 2015). The use of HCl alone for acidization, especially in higher temperature reservoirs, has suffered some signal failures. A large volume of acid is required because the rapid reaction of the acid

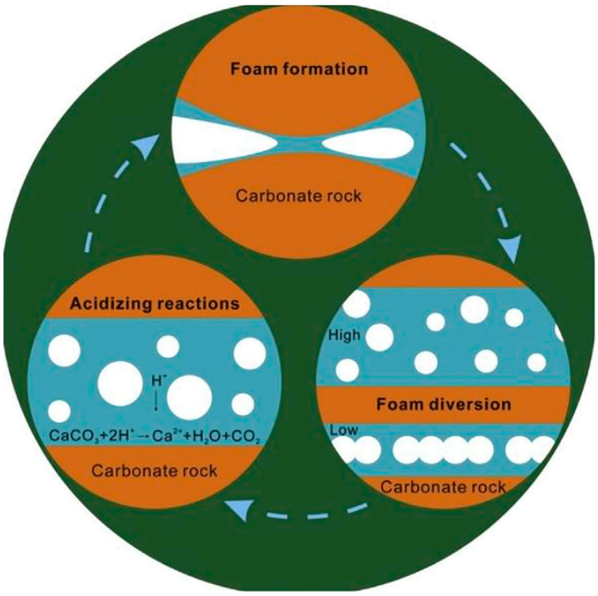

FIGURE 1
Induced acid diversion by foam-based acid (Yan et al., 2019).

with the carbonate minerals of the formation consumes acid at a far faster rate (Chavez, 2007). Due to the shorter residence time of the acid in the formation, especially at high temperatures, the wormholes created are less efficient hydrocarbon channels (Chacon and Pournik, 2022). Therefore, gelled acid, foamed acid, micro-emulsified acids, and other chemical agents have been formulated in an effort to circumvent the drawbacks of the fast acid-rock reaction by lowering H^+ ion dissociation, reducing H+ ion mass transfer, and changing the wettability of the rock surface (Zhu et al., 2022).

Comprehensive review

Gelled acid

The gelled acid fluid is comprised of water, a water-dispersible polymer, an acid, and a gelling agent (Chang et al., 2007; Ismail and Kweh, 2012). Two types of polymer-based acid have been used in the field for matrix acidization: gelled acid for acid retardation and *in situ* gelled acids for acid diversion. The *in situ* formulation includes polymers or VES, crosslinkers, and pH-controlled breakers to achieve dissolution by preventing the acid from passing through highly permeable zones and diverting it to less-permeable zones (Ratnakar et al., 2012; Gomaa and Nasr-El-Din, 2015). In matrix acidization, the gelled acid relies on the viscosity difference of the fluid to reduce the mass transfer of H^+ ions and consequently the acid reaction rate. The use of polymers as viscosifiers poses a challenge, however, because of the buildup of residual chemicals in the formation, which can damage it (Chang et al., 2007).

Micro-emulsified acid

The formulation of a micro-emulsion acid requires that the hydrochloric acid is the internal phase and that the hydrocarbons (crude oil and diesel) act as the external phase (Zakaria et al., 2015). The hydrocarbons reduce the diffusion rate of the HCl droplets and lower the dissolution rate of the rock surface, thus generating highly permeable wormholes (Carvalho et al., 2019). The use of micro-emulsified acid has an advantage over other matrix acidizing methods in that it creates more conductive channels and reduces the mobility or effective diffusivity of HCl without jeopardizing the formation productivity (Fredd et al., 2016). A transient skin factor is created in the high permeability zones, thus diverting the acid to the lower permeability zones (Liu et al., 2013). The reduction in contact time and area between the acid and the casing and tubing minimizes corrosion (Liu et al., 2013; Derendyaev et al., 2022).

Foamed acid

Foamed acid is formed by mixing acid and surfactants and injecting gas (N_2/CO_2). Compared to traditional acidizing processes, foaming has the advantages of diversion, moderate speed, low water sensitivity, increased energy to assist discharge, and less damage to the formation; thus, foam diversion acidizing technology has attracted much attention in recent years (Motta et al., 2021; Yuan et al., 2021). Foamed acid may be used to uniformly treat the entire formation by temporarily limiting acid access to the higher permeability zones and channeling it to the less permeable zones (Letichevskiy et al., 2017; Yan et al., 2019). In comparison to typical acid treatments, foamed-VES formulations have shown excellent acid diversion performance and also pose little threat of formation damage because they contain no polymers (Chang et al., 2007; Yan et al., 2019). They also contain no solids that could impair permeability, and the gas expansion in the foam allows easy flow back during well cleaning (Chang et al., 2007). The retarding action of foaming slows down the speed with which the acid reacts with the rock, resulting in deep matrix acidification (Stringfellow et al., 2017; Zhang et al., 2021).

Conclusion

Due to the fact that carbonate reservoirs are heterogeneous with varied permeability zones and a high temperature environment, the selection criteria for choosing one of the three proposed matrix acidizing methods must be careful observed. Various researchers have reported that foam-based acids were superior to traditional acidizing methods. They provided effective diversion, reduced the acid reaction rate and water sensitivity, increased energy for discharge of acid into the formation, and caused less harm to the formation. Foaming lowered the effective acid diffusion coefficients into the formation, thus regulating convection and diffusion rate. Foamed acid remains in contact longer with the less permeable zones of the formation, and the process prevents the carbonate-acid reaction from happening too rapidly in the highly permeable zones. At low injection rates, the poor diffusivity of micro-emulsified acid produces narrow but deeper effective wormholes.

The gelled acid relies on viscosity differences in the fluid to reduce the mass transfer of H^+ and the acid reaction rate. Despite its good volumetric efficiency and acid diversion tendency, the field application of gelled acid is limited by the buildup of residuals that impair the flow of oil back through the wormholes to the wellbore. The polymers used as viscosifiers can remain as residual chemicals in the formation and lead to damage; therefore, VES formulations are preferred.

Author contributions

CW: investigation and research, writing manuscript draft; LZ: resources and conceptualization; BH: modify analysis; XZ: typesetting; AM: supervision.

Conflict of interest

Author BH was employed by Zhenhua Oil Co. Ltd.

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