**Introduction**

Acidizing is commonly performed on wells to remove damage and reduce skin to maximize productivity and recovery. Acidizing enhancement technique is still a highly preferred method of damage removal/stimulation adopted for sandstone and carbonate reservoir dating as far back as the nineteenth century. A proper acid design program is critical to success of these types of treatments. However, proper placement technique carries the same importance as the acid design. Using a new placement technique, the entire planned completion interval can be acidizing at sufficient injection rates without exceeding the formation ability to accept fluid below the fracture gradient. When acid is pumped into damaged reservoir for damage removal/stimulation, distorted inflow of acid into formation occurs caused by preferentially traveling into highly permeability regions over low permeability regions or into the path of least resistance. If acid is not effectively diverted in formation with high permeability/fracture anisotropy, some treated zones may become acid sinks while other zones are left with inadequate acid stimulation.

**Acidizing Challenge**

Reservoir and wellbores are interconnected by pores in the formation. The flow of fluids through these pores is often restricted because of permeability damage in the near wellbore formation caused by drilling fluid invasion, cementing and completion operation that reduce the physical size of pore throats or block the pore space causing impairment to the reservoir permeability that often-called formation damage.

Acid treatment falls into three general categories:

- **Wellbore cleanout** – remove debris that block pore space during installation
- **Matrix acidizing** – pump below formation pressure
- **Fracture acidizing** – pump above formation pressure

Wellbore cleanout is processed to clean the tubular and wellbore with acid to clear out debris that block the pore space due to drilling operation. Matrix acidizing is an acid treatment injection at matrix pressure and staying below formation fracture pressure. In sandstone formation, it is used to remove or dissolve acid removable damage in the formation pore network near wellbore or to remove plugging in the perforation. In carbonate formation, matrix acidizing works by forming conductive channels called worm holes through the formation rock.

There are three type of matrix treatments:

- **Near wellbore stimulation** – within 2ft to 3ft of the wellbore
- **Intermediate matrix stimulation** – within 3ft to 6ft of the wellbore
- **Extended matrix acidizing** – further than 6ft from wellbore and use large volume

Ideally, when acid is pumped into zones of variable permeability, it will distribute equally into all zones. However, in general, acid preferentially flows into path of least resistance which is the high permeability regions over low permeability regions as shown in Figure 1.

![Figure 1. Acid preferentially flows into least resistance path.](image)

When acid is flow into high permeability/fracture zones compared to low permeability zone, consequently the damage in the high permeability zones will be removed at higher rate hence the skin is drastically reduced. Such a distorted flow results into over-threating a high permeability zone leading to poor zonal coverage as shown in Figure 2. In this case, the low permeability zone is poorly treated with acid resulting in poor production recovery. The high permeability zone could also lead to excessive flow contribution that resulting in water or gas conning.

![Figure 2. Over-threating a high permeability zone resulting in poor distribution to low permeability zone.](image)
FloFuse acidizing technique

Acid diverter is one of the acidizing techniques that could be used to distribute acid in well. The choice of diverter method depends on its applicability, well characteristic and reservoir property. However, existing method need a mechanical isolation device to temporary straddle the fracture zone and this often associated with high cost and more operation time. Limited entry liner is another diversion technique that been adopted in long horizontal well. The limited entry is achieved by proportioning the number of perforations according to the thickness of the pay zone. However, this technique has significant challenge if fracture location is unknow as it unable to isolate the fracture zone.

FloFuse is an autonomous acid divertor device which is biased open valve which enables acid injection at normal distributed rates. The Flofuse is mounted into the basepipe or screen section and required zone isolation to distribute the outflow of the acid as shown in Figure 3. The placement of the flofuse could be simulate in modelling to show equal distribution of acid as shown in Figure 4.

If the acid is injected into fracture of high permeability zone, the acid will preferentially flow at higher flowrate that will exceeded the ‘trigger rate’ and choke the valve. Once the FloFuse is triggered, outflow is highly constrained into the ‘fused’ zone enabling acid injection to be diverted into the other compartments as shown in Figure 5. The fuse zone could be indicate with higher pressure drop due to higher flow rate at fracture zone cause the FloFuse stop flowing to “fuse zone” as shown in Figure 6.

Once the effected flofuse “fuse”, it will increase the well head pressure to indicate a particular zone have completed acidizing and the need of reduction of flowrate. The “fuse” process will keep continue as a new zone increase in permeability as shown in Figure 7 and 8.

When all the zone has been given the desired amount of acids treatments and become very permeable zones. All flofuse will be in choke/shut in position as shown in Figure 9. The fuse effect could be observed with rapid increase in well head pressure that indicate all zone have been acidize at optimum rate without over threatening any of the zone. This technique will also avoid any excessive use of acid. Figure 10 shows a optimization modelling example between wellhead pressure and injection rate to shows injection process.

The FloFuse is fully reversible and the valve will re-set if injection is stop and differential pressure across the valve decrease. The acidizing process could be repeated if further acid treatment is desire and the rate become sufficiently distributed again.
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Figure 10. FloFuse optimisation modelling

FloFuse device

The target normal operating rates and degree of outflow control and trigger rates and can be varied by application. Figure 11 show the cross section and key features of the valve in open position.

If the formation have fracture or high permeability, the injection rate into that compartment will increase. The resultant increased pressure drop through the nozzle acts against the spring until the flow area between the seal face and the nozzle becomes restricted and the valve triggers to the fused position restricting the outflow into that compartment as shown in Figure 12.

Figure 12. FloFuse in close position, main nozzle slide to sealing face

Under normal operating conditions injection outflow passes through the main nozzle and into the formation. In case sand control is needed, the outflow will be injected into the housing and through the screen as required as shown in Figure 13.

Summary

Acidizing of sandstone and carbonate reservoir is a common practice to ensure high productivity by removing the near wellbore damage. A new autonomous acid stimulation device, FloFuse is developed to choke back the acid injection treatment into natural/induced fractures and mitigate the disproportional injection of acid into the fracture/high permeability zone. Flofuse device improved acidizing treatment efficiency by autonomously shut in the injection into fracture zone and divert the flow to another untreated zone. Flofuse stop over threatened to high permeability area or fracture reduce the waste of acid and improved the economic of acidizing. Optimization of Flofuse acid treatment design have been simulated in reservoir modelling.