CLOGGING REHABILITATION AND REMEDIATION METHODS

Clogging Remediation Methods to Restore Well Injection Capacity

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Abstract

A MAR scheme will invariably experience clogging of some type, and to some degree, during its operational life. To recognise the potential for clogging and employ the appropriate mitigation or remediation measures, either through engineering design or through operational management practices, requires specialist knowledge and skills. It should also be noted that remediation methods to address clogging are very site specific and what works in one hydrogeological setting may not always be successful in another location. Indeed remediation approaches may differ between injection bores across the same scheme. This paper presents an overview of some of the approaches that can be adopted to remediate bores once clogging has occurred.

Introduction

Clogging is an ever present issue facing many operators of managed aquifer recharge (MAR) schemes and can result in lost harvesting opportunities where the scheme is shut down for extended periods to carry out remediation activities, often at significant cost.

Frequently, clogging that leads to the failure of a MAR scheme occurs from a lack of proper aquifer characterisation resulting from 1) poor data collection and organization; 2) little or no integrated analysis of existing data by experienced geological and engineering personnel; 3) failure due to inexperience of practitioners to consider remediation methods; 4) engagement of multiple sub-contractors by the proponent during the various stages of investigation, design, construction and operation that typically results in problems at the interface of each work package; and 5) not identifying optimum management techniques to prevent clogging or allow for remediation in the event of it occurring.

This section deals primarily with remediation methods that can be employed to restore and improve injection capability within recharge wells. It should be noted that the well remediation methods presented herein are not exhaustive, for example, there are proprietary techniques developed by experienced ASR practitioners that are not discussed.

To adopt the correct remediation method requires adequate and detailed aquifer characterisation during the initial site investigations followed by reliable monitoring during operation. It is becoming increasingly apparent that inexperienced practitioners are failing to adequately characterise the target aquifer which is leading to poor well design and poor selection of casing materials thereby limiting the options for well remediation when clogging arises. There is a real risk that poor practice increasingly puts at risk the uptake of MAR as a viable and effective water resources management tool.

There are various measures that can be incorporated to minimise clogging and prolong the operational life of the well ranging from engineering through to operational controls. These preventative measures include:

- Selection of appropriate drilling methods and drilling fluids to avoid formation damage.
- Appropriate development of the well on completion of drilling and casing installation.
- Selection of the appropriate well design for the target aquifer.
- Periodic backwashing of the recharge wells at specified times or volumes recharged.
- Removal of air from the recharge water using dissolved oxygen scrubbers or through the addition of carbon dioxide.
- Eliminating as much as reasonably possible the potential for air entrainment in the recharge water within the MAR scheme infrastructure.
- Periodic or constant chemical dosing to treat for algae and microbiological activity.
- Ultra filtration (membrane and Ultra Violet treatment) prior to recharge via the well.
- Reverse osmosis pre-treatment and ultra-filtration if wastewater is the primary recharge water source.

- Chemical treatment to aid in flocculation of suspended sediments followed by ultra-filtration to improve source water quality.
- Management of operating pressures to prevent failure of the target aquifer.
- Periodic dosing to prevent the build-up of scale within the pipe networks and wells.
- Following dosing of pipes and other infrastructure to remove scale or other build-up "pigging" may be required.
- Eliminating the potential for sub-surface geochemical reactions through pH adjustment or salinity adjustment.

The preventative measures selected will largely depend on the source water, the receiving water and the mineralogy of the host aquifer. Despite the incorporation of effective preventative measures it is still highly probable that at some point during its operational life the MAR scheme will experience clogging that will require more extensive remediation.

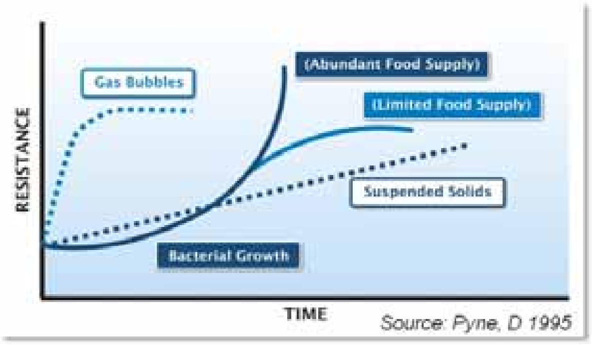
Identifying the onset of clogging

Practitioners should always consider the potential for serious clogging and the types of remediation methods that are appropriate for the hydrogeological setting as this will influence the well design and the selection of materials used during construction. A well may experience several years of operation before any loss in injection efficiency becomes apparent. Clogging due to microbiological activity, geochemical reactions, air entrainment or mechanical blocking causes an increase in friction losses near the well bore or screen and the specific capacity is reduced.

Recording the aquifer hydraulic response during recharge via a well provides the first indication of the onset of clogging. Figure 1 presents the typical hydraulic responses (Pyne, R.D.G., 1995) that are observed for some of the clogging types that occur in wells used for MAR. The characteristic hydraulic response curves hold in general, but it is not uncommon for the hydraulic response associated with the mobilisation of insitu fines to be similar to the clogging hydraulic response that may be observed where microbiological populations have an abundant food supply. The subtle difference that points to the mobilisation of insitu fines is that as with suspended solids the early response of hydraulic head (resistance) with time is likely to be linear before becoming exponential.

Monitoring of source water quality in-line (turbidity, pH, Electrical conductivity), injection rates and the aquifer hydraulic response, in both the injection well and any associated observation wells, is critical as often multiple clogging processes may be acting in concert. Without identifying and treating the primary cause the associated types of clogging may continue to cause operational issues.

Figure 1: Aquifer hydraulic response associated with the different clogging types (after Pyne, R.D.G., 1995)



Remediation Methods

Airlift Development

Airlift development procedures are one of the most common methods for remediating wells, both during completion and also to clean out wells following the onset of clogging. Airlift development procedures should begin by determining that groundwater can flow freely into the well. Application of too much air volume in the recharge well when the formation is clogged can result in a collapsed screen (Driscoll, 1986).

Where wells have been completed using a screen, during development, the air line should initially be placed at a relatively shallow submergence and high above the screen to minimise the potential for the screen to collapse. By placing the air line at a shallow submergence, even with large air volumes, only a low collapse pressure can be applied to the screen. Once a steady uninhibited flow into the well is achieved the air line can be steadily lowered to within a metre of the top of the screen. Airlifting should continue until the water discharged from the well is free of any suspended solids.

If clogging of the screen or formation has occurred as a result of fine sediments then it may be advantageous to pre-treat the well prior to using airlifting of jetting with a number of the chemicals (e.g. Kalgon) that can assist the breakdown of the sediment particulates.

It may seem counter intuitive to remediate a well through airlifting as one of the primary causes of clogging is air entrainment. However provided the air line remains above the screen air will invariably be forced up the drillhole rather than into the formation. Cleaning of the screen is achieved by the sudden inrush of water from the aquifer to replace the water expelled out of the top of the well.

Air lift development should be avoided in aquifers that are prone to “air locking” such as stratified formations consisting of coarse sand or gravel lenses separated by thin, impermeable clay layers. “Air locking”, as with air entrainment in general may impede the flow of water into and from the well, while also increasing the potential for iron precipitation within the formation thus creating a secondary clogging issue.

High Velocity Jetting

Jetting involves injection of compressed air or water at the bottom of the well, and the accumulated sediment is forced out the top. The frequency with which recharge wells should be cleaned will vary greatly depending on the sediment load from the site and the depth of the well.

The jetting procedure consists of operating a horizontal water jet inside the well screen so that high velocity streams of water shoot out through the screen openings. Jetting is extremely successful in developing highly stratified, unconsolidated formations. The equipment required for jet development includes a jetting tool with two or more equally spaced nozzles, high pressure pump, high pressure hose and connections, pipe, and water tank or other water supply. Material loosened from the screen or formation accumulates at the bottom of the screen (or in the sump if included in the well completion design) as the jetting tool is raised slowly. This material is removed later by airlift pumping (Driscoll, 1986).

Vacuum Pumping

Vacuum pumping involves a dual pipe system. Air is forced down the inner tube and returns up the annular space between the inner and outer tubing. As the outer tubing extends past the inner tube outlet a vacuum is created and sucks up the fine material that has accumulated on the walls of the formation. It is an extremely effective method if there are concerns about introducing air into the formation.

Vacuum pumping is only suitable for wells where there is no gravel pack or screen. As in some cases the high inflow velocity generated is higher than the average calculated for a screen dimension and slot size, and a concentration of clogging can be induced behind the screen in this high-velocity zone.

Acidisation

Acidising is typically performed to increase formation permeability in undamaged wells; however, it can be applied to improve injection performance in wells that have become clogged by either particulate matter or through microbiological activity. Care needs to be taken when acidising as sometimes additional fines are mobilised through the dissolution process. Furthermore a propping agent may need to be used to maintain the stability of the aquifer matrix and keep the formation open after dissolution.

An ideal acidising fluid is able to penetrate long distances, etch fracture faces, increase the permeability of the matrix where the fluid enters the formation by diffusion, and remove any existing formation damage.

A number of different acids are used in conventional acidising treatments. The most common are:

- Hydrochloric, HCl
- Hydrofluoric, HF
- Acetic, CH_3COOH
- Formic, $HCOOH$
- Sulfamic, H_2NSO_3H
- Chloroacetic, $ClCH_2COOH$.

These acids differ in their characteristics. Choice of the acid and any additives for a given situation depends on the aquifer matrix characteristics and the specific intention of the treatment, for example, near well damage removal, dissolution of scale in fractures, etc.

Portier et al. (2007) outline a number of factors controlling the reaction rate of acid:

- area of contact per unit volume of acid;
- formation temperature;
- pressure;
- acid concentration;
- acid type;
- physical and chemical properties of formation rock; and
- flow velocity of acid.

Hydrochloric acid and hydrofluoric acid are the two most common acidizing treatments. However, the very fast reaction rate of hydrochloric acid, and other acids listed above, can limit their effectiveness in a number of applications. All conventional acids including HCl and organic acids react very rapidly on contact with acid sensitive material in the well or formation. “Worm-holing” is a common phenomenon. The rapid reaction means the acid does not penetrate very far into the formation before it is spent. Conventional acid systems are therefore of limited effectiveness in treatments where deep acid penetration is needed.

Portier et al. (2007) discuss acid stimulation in significant detail including the addition of polymers and surfactants to retard acid reaction rates and achieve deeper formation penetration of the acid before it is spent.

Less known and less used than either HCL or sulfamic acid, hydroxyacetic acid is safer to use and has the benefit of being a bactericide and will directly attack and kill iron bacteria. It works the slowest of the HCL, Sulfamic or Hydrofluoric acids, so its contact time in the well will be the longest to achieve the desired effect. Hydroxyacetic acid is relatively non-corrosive and produces no fumes.

Biocides

Where Environmental Protection Agency regulations permit, shock chlorination may be used to limit the growth of iron bacteria and other microorganisms. The shock chlorination approach is widely used in the rehabilitation of wells severely plugged by biofouling bacteria. Concentrations as high as 500 to 2,000 ppm are used. Once injected into the well, water is added to force the chlorine mixture out into the formation. Agitation is always recommended to increase surface contact between the biofouling agents and the high concentration chlorine solution. Mechanical brushing, agitation, surging and jetting are all used to increase the turbulence of the chlorine solution in the well. Shock chlorination may be used as the first step, then acidisation of the well (note- the well must be fully purged of the chlorine solution before acidisation) with agitation to improve removal of encrustation, and thirdly another shock chlorination treatment.

Chlorine based approaches are more effective the longer the contact time between the chlorine solution and the biofouling agents. Disposal of the waste water after both the shock chlorination and the acidisation must be done with awareness of safe disposal procedures.

Under-reaming

Where a well hole has been completed as an open hole construction and under-reamer can be used to enlarge the well beyond bit diameter. Assuming that the clogging has occurred primarily within the first few centimetres of the aquifer matrix the under-reamer can be used to effectively create a fresh well face by removing the clogged section of the aquifer. An under reamer can be opened and closed several times down hole, making it easy to enlarge the well hole over specific sections.

This approach is useful where jetting or airlift development have failed to improve the injection capacity of the well.

Scrubbing

Wire brushing and scraping are effective means for removing encrustations from inside the casing and well screen. The loosened material can be removed by air lifted, bailing, or other means. This approach may be a good first step in rehabilitation as it may allow greater access to the formation for chemicals to be introduced later if the scrubbing fails to improve well injection capacity.

In some cases it may be difficult to find a drilling contractor that has the appropriate tools necessary to scrub the casing and screens. Where such an activity is undertaken it may be necessary to shut down or scale back the injection operations in any nearby wells so that the bore can be effectively worked on.

Heating

Heat can be used to increase the effectiveness of chemical treatments in well rehabilitation. Water is withdrawn from the well, heated and recirculated into the well to increase the action of chemical solutions. Several specialists in rehabilitation routinely employ heated chemical treatments as part a blended of a multi-step approach to well remediation. Heat alone can also be an effective biofouling removal method where chemicals cannot be used.

Summary

A rule of thumb is that if the injection capacity of a well has declined by about 25%, it is time to begin rehabilitation efforts. The earlier the rehabilitation commences the more efficient and cost effective the remediation will be. Down time of the scheme and thus lost harvesting opportunities can also be kept to a minimum. The approach to be adopted for the well remediation will be determined by the clogging type, well construction and target aquifer mineralogy. Not all remediation methods are suitable for every site and indeed different remediation methods may need to be adopted for different wells within the same well field.

A multi-step or blended approach to rehabilitation that involves combinations of mechanical brushing, agitation, surging and/or jetting produces a superior result.

Acidisation and other remediation methods such as shock chlorination should only be carried out by experienced practitioners. In some cases this may present a barrier to the implementation of an ASR scheme as there may be an insufficient number of experienced practitioners available that have the skills or the equipment necessary to carry out the remediation work. Therefore, this presents a potential risk to the sustainable operation of the schemes when significant capital may have been invested and there are insufficient local skills to effectively rehabilitate the wells when required.

To determine the effectiveness of the adopted remediation action some reference point is needed. Typically this is the aquifer hydraulic properties in particular specific capacity, prior to the commencement of injection. It is recommended as a minimum to undertake a step drawdown aquifer discharge test on all injection wells that can then be used as the performance baseline against which clogging and remediation effectiveness can be assessed.

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