GAS OR HYPO OR SOMETHING ELSE?

Information for water service providers to support management decisions on disinfection options

July 2018

Executive Summary

The majority of Queensland water and sewerage schemes use chlorine for disinfection. Chlorine gas and liquid sodium hypochlorite are by far the most commonly used chlorination chemicals, with chlorine gas generally but not exclusively favoured by the larger service providers and for large water and sewerage schemes, and sodium hypochlorite for smaller, often regional and/or remote, providers and schemes.

Many service providers use different types of chlorine for different schemes. There appears to be growing uptake of calcium hypochlorite disinfection systems with the increased availability of sophisticated automated dosing systems and improved low technology options, and there are of course disinfection options other than chlorine used to provide additional treatment barriers by targeting particular pathogens.

Chlorine gas, sodium hypochlorite and calcium hypochlorite each have their advantages and disadvantages in terms of cost, operability and operator safety. Within the water industry, there is increasing discussion between operators, regulators, governments and suppliers about the relative merits of chlorine gas and sodium hypochlorite in particular, and enough anecdotal evidence to suggest that water businesses might decide to change existing disinfection processes based on incomplete information.

This discussion paper provides local government decision makers with information to help them make informed choices about disinfection options for their water and sewerage schemes.

It addresses the pros and cons of disinfection using chlorine gas, bulk liquid sodium hypochlorite, on-site generated sodium hypochlorite, and solid calcium hypochlorite. It is not a substitute for site and source-specific advice, instead intended as a tool to help ask the right questions of contractors and consultants, and encourage third party review of options offered to achieve the right balance of operator and public safety, costs to install and operate, ease of operation and ultimately drinking water quality.

Table 1 gives a high-level summary of the risks associated with each of the chlorine disinfection options.

It is important to recognise that the outcomes will differ significantly depending on the size and location of the drinking water or sewerage scheme. For sewerage schemes, chlorate formation in liquid sodium hypochlorite over time is not a significant issue, but the reduced disinfection capability is.

Table 1: Summary of risks associated with chlorine disinfection options

Red	HIGH RISK
Orange	MEDIUM RISK
Yellow	LOW RISK

	Chlorine gas	Sodium hypochlorite - bulk	Sodium hypochlorite - on site generation	Calcium hypochlorite
General suitability (on balance) for different sized treatment schemes				
Large	Low	Low	High	High
Small - medium	Low	Low	Medium	Medium
Very small, remote	High	Medium	Low	Medium
Costs				
Capital (large installations)	Medium	Medium	High	Medium
Capital (small installations)	High	Medium	High	Medium
Chemical	Low	High	Low	Medium
Maintenance	Medium	Medium	High	Medium
Chemical Safety				
Storage / regulation	High	Medium	Low	Medium
Worker safety	High	Medium	Low	Medium
Community safety (near site)	High	Low	Low	Low
Environmental safety (near site)	Medium	High	Low	Medium
Ease of use				
Complexity	Medium	Medium	Medium	Medium
Servicing and calibration	High	High	High	High
System reliability	Medium	Medium	Medium	High
Attendance / monitoring	High	High	High	High
Chemical stability, effectiveness as disinfectant				
Chlorine concentration	Low	High	Medium	High
Chlorate formation	Low	High	Medium	Medium
DBP formation	Medium	Medium	Medium	Medium

What is disinfection and why is it important?

Disinfection is the process of killing microbial pathogens, or disease causing organisms. These include bacteria, viruses and protozoa, particularly cryptosporidium and giardia.

Water treatment involves multiple steps or "barriers," each of which excludes some pathogens and contributes to the quality and safety of the final product. The individual steps that make up a water treatment process vary greatly from scheme to scheme, but the vast majority have one barrier in common; disinfection. Effective disinfection is fundamental to producing safe drinking water, and its failure brings a high risk of endangering public health by supplying unsafe drinking water.

Disinfection also plays an important role in wastewater treatment by killing the pathogens that could endanger the health of people who come into contact with treated effluent, be that by incidental recreational exposure, or contact with recycled water.

Why single out chlorine?

A number of proven disinfection options are available to water and sewerage service providers. As well as chlorine, chloramine, chlorine dioxide, ozone and ultraviolet radiation are all effective disinfectants.

However, for reasons that include historical precedent and familiarity, capital and operating costs, availability, ease of measurement, reliability, relative simplicity, and the benefits of maintaining a network residual (capacity to keep killing pathogens beyond the treatment plant), chlorine has been and remains the disinfectant of choice for the majority of Queensland water and sewerage service providers.

Accordingly, this discussion paper focuses on chlorine disinfection.

Isn't chlorine just chlorine?

As used in water and sewage treatment, chlorine comes in 3 forms:

- Chlorine gas (Cl_2);
- Liquid sodium hypochlorite (NaOCl); and
- Solid calcium hypochlorite ($Ca(OCl)_2$).

The disinfectant action is the same in all cases. The chlorine containing chemical reacts with water to form the powerful disinfectant hypochlorous acid (HOCl). However, each of the different chlorine options brings its own advantages and disadvantages, which are discussed below.

An alternative form of chlorine disinfection is chloramination. Chloramines are formed when chlorine and ammonia are added to water. Compared to hypochlorous acid, chloramines have a less powerful disinfectant action but are more persistent, meaning that chloramination is sometimes used for water schemes that experience long detention times. Chloramination (in widespread use in South-East Queensland) is more technically challenging than simple chlorination and requires careful management of the chlorine to ammonia dose ratio to form monochloramine in preference to dichloramine and trichloramine, which are less powerful disinfectants and cause objectionable tastes and odours when present, even in small amounts.

Chlorine is a strong oxidising agent

As well as being a very effective disinfectant, chlorine is a strong oxidising agent, which means that it readily reacts with a range of organic and inorganic chemicals in the water. This reactivity brings benefits and disadvantages.

On the plus side, chlorine's reactivity means that it can oxidise some non-biological contaminants (notably dissolved iron and manganese) in the water, making them easier to remove. It can break down some dissolved organic chemicals that cause tastes, odours and colour in water and can destroy some cyanobacterial toxins.

However, chlorine (and other disinfectants) can also react with dissolved organic material in the water to form disinfection by-products (DBP). These include trihalomethanes (THMs), haloacetic acids, haloacetonitriles and trichloroacetaldehyde.

DBP formation is highly variable and the types and concentrations of DBP formed are influenced by the disinfectant type, the nature and amount of dissolved organic material present, the water chemistry (such as pH, temperature and bromide concentration) and residence time in the water network. The Australian Drinking Water Guidelines (ADWG) includes health based guideline values for a number of DBPs.

Every effort should be made to manage the disinfection process to minimise DBP formation, but the bottom line is that pathogenic organisms in drinking water pose much the greater and more immediate risk to public health and effective reduction of pathogens must always take priority.

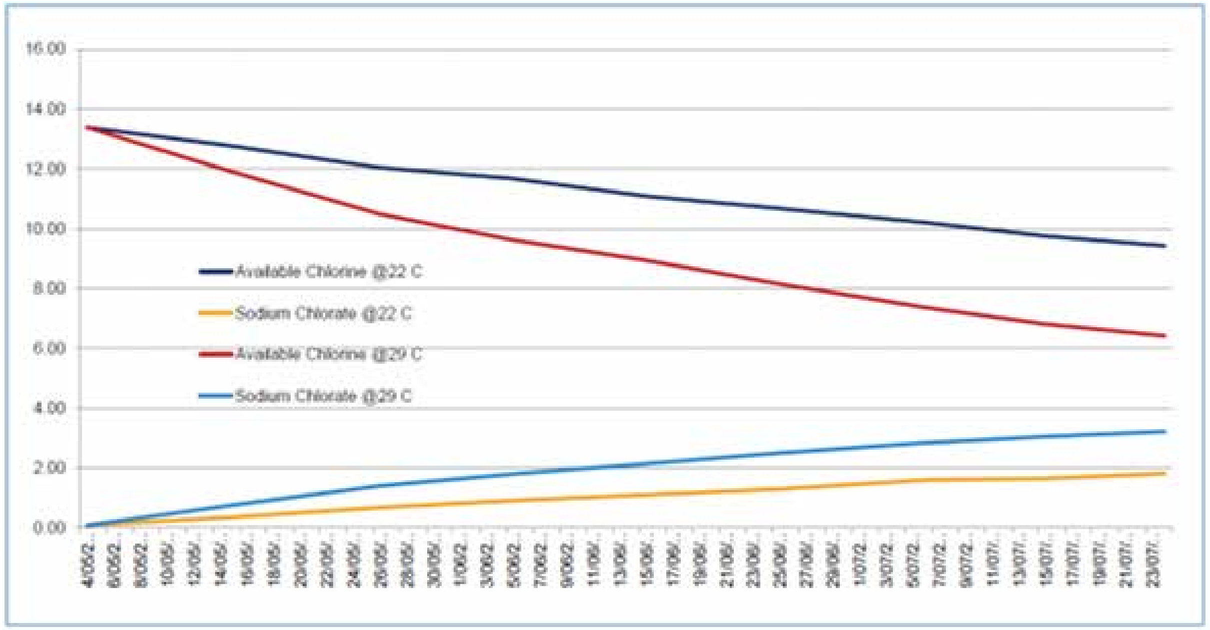
The chlorination options

	Chlorine gas	Sodium hypochlorite - bulk liquid	Sodium hypochlorite - generated on site	Calcium hypochlorite
What is it?	Liquefied chlorine gas (100%) commonly delivered in 70 kg and 920 kg pressurised containers.	Bulk solution of sodium hypochlorite in water, usually 10.0% - 12.5% available chlorine. Sodium hydroxide is added to improve stability, resulting in high pH (11+).	0.8% sodium hypochlorite solution. Generated on-site by electrolysing brine solution. Inputs per kg Cl_2 equivalent: Salt 6.6 kg Softened water 125.2 L Electricity 4.4 kWh	Available in bulk granular, tablet or briquette forms, typically 65%-70% available chlorine.
How stable is the chlorine content?	Does not degrade over time.	Degrades over time – 15% available chlorine degrades to 13% after 20 days and 10% after 100 days. Degradation rate slows significantly below 10% available chlorine. Degradation accelerates in the presence of UV light, Fe, Cu, Co, Ni impurities. Chlorine off-gassing may occur. Chlorates formed as degradation by-products – possible health risk, possible future ADWG health based guideline.	Very stable compared to commercial bulk sodium hypochlorite solution. Minimal degradation over time. Greatly reduced risk of chlorate formation.	Highly stable in solid form. Degrades in solution if stored for more than a few days.
How safe is it?	Highly toxic gas - highly regulated. Classified as DANGEROUS GOODS under ADG Code – Toxic gas (2), Oxidising Agent (5.1), Corrosive (8). Classified as a HAZARDOUS CHEMICAL by Safe Work Australia.	Corrosive liquid. Classified as DANGEROUS GOODS under ADG Code – Corrosive (8). Classified as a HAZARDOUS CHEMICAL by Safe Work Australia. Releases chlorine gas on contact with acids or heating. Incompatible with metals – storage and dosing system materials requirements. Highly toxic to aquatic organisms. Spills pose significant environmental risk.	Corrosive liquid. Classified as DANGEROUS GOODS under ADG Code – Corrosive (8). Classified as a HAZARDOUS CHEMICAL by Safe Work Australia. Releases chlorine gas on contact with acids or heating. Incompatible with metals – storage and dosing system materials requirements. Falls below 1% concentration threshold for classification as hazardous. Electrolysis process produces hydrogen gas by-product – potentially explosive.	Classified as DANGEROUS GOODS under ADG Code – Oxidising Agent (5.1). Classified as a HAZARDOUS CHEMICAL by Safe Work Australia. May intensify fire. Releases chlorine gas on contact with acids or heating. Causes severe burns and eye damage on contact. Needs to be kept away from organic materials. Highly toxic to aquatic organisms. Spills pose significant environmental risk.

The chlorination options (continued)

What are the installation and main-tenance issues?	Installations must comply with AS/ NZS 2927:2001 The storage and handling of liquefied chlorine gas. Low-level chlorine leaks in the presence of moisture can result in the corrosion of fittings and potential for uncontrolled chlorine gas releases.	Installations must comply with AS 3780-2008 The storage and handling of corrosive substances.	Product hypochlorite storage must comply with AS 3780-2008 The storage and handling of corrosive substances. Installation must incorporate dilution of hydrogen gas by-product in air before discharge.	Granular calcium hypo-chlorite must be dissolved in water before dosing. Calcium hypochlorite tablets can be dosed manually or using commercial tablet feeders. Calcium hypochlorite briquettes can be dosed manually or using commercial dissolution systems. Commercial calcium hypochlorite contains significant amounts of inert and insoluble materials that can result in increased maintenance costs due to line and pump blockages.

The graph below shows how sodium hypochlorite concentration decreases and chlorate concentration increases with storage time and temperature [1].



Cost comparison

	Chlorine gas	Sodium hypochlorite - bulk liquid	Sodium hypochlorite - generated on site	Calcium hypochlorite
Capital Costs	Lower for large installations. Mandated safety requirements increase cost per ML for smaller installations. Package systems available.	Relatively higher. Cost over gas decreases with decreasing treatment capacity. Package systems available. Large installations need heavy vehicle access for bulk chemical delivery.	High. Needs reliable power supply. Large installations need heavy vehicle access for bulk salt delivery. Higher capacity dosing system required due to low product concentration.	Low for low technology tablet dosing systems. Similar to or less than bulk sodium hypochlorite for granular and briquette dissolution systems. Higher capacity dosing system required due to low product concentration.
Chemical Costs	Low.	Higher compared with gas.	Approximately 1/3 cost of bulk sodium hypochlorite. Cost of electricity may vary.	Lower than bulk (liquid) sodium hypochlorite.
Freight Costs	Moderate – extra cost from specialised transportation due to ADG classification. Minimum delivery size may apply.	Extra cost from specialised transportation due to ADG classification. Higher freight costs than gas due to high water content. Minimum delivery size may apply.	Freight costs due to salt consumption (but not additional associated with dangerous goods).	Extra cost from specialised transportation due to ADG classification.
Main-tenance Costs	Moderate - Regular maintenance fittings and safety systems. Monitoring and reporting costs. Ongoing specialised training required.	Moderate - Regular maintenance pumps, fittings, delivery plumbing. In-house possible. Pump calibration.	High - On-site generation system requires specialised maintenance. Delivery system as per bulk.	Moderate. Dissolved calcium hypochlorite dosing system as per sodium hypochlorite. Risk of dosing pump and lines may increase maintenance frequency.

Chemical stability and drinking water safety and quality

	Chlorine gas	Sodium hypochlorite - bulk liquid	Sodium hypochlorite - generated on site	Calcium hypochlorite
Chlorine concentra-tion	Does not change with storage.	Decreases with extended storage. Rate of decay increases with solution strength, temperature and exposure to sunlight. Relatively stable below 10% available chlorine. Can off-gas.	Stable due to low sodium hypochlorite concentration in product.	Stable if stored correctly but chlorine content can reduce significantly over time if not stored in closed containers.
Chlorate formation	Does not occur.	Chlorates form as sodium hypochlorite breaks down. Potential water safety risk.	Minimal due to stability of low strength sodium hypochlorite solution.	Minimal.
DBP formation	Yes	Yes	Yes	Yes

Safety

	Chlorine gas	Sodium hypochlorite - bulk liquid	Sodium hypochlorite - generated on site	Calcium hypochlorite
Installation require-ments	AS/NZS 2927:2001 The storage and handling of liquefied chlorine gas.	AS 3780-2008 The storage and handling of corrosive substances. Inert materials required. ADG segregation requirements.	AS 3780-2008 The storage and handling of corrosive substances. Inert materials required.	AS 3780-2008 The storage and handling of corrosive substances. Inert materials required. ADG segregation requirements.
Workplace health and safety	Toxic gas. Specialised PPE and training (including BA) for changing cylinders and responding to leaks. Gas detectors and alarms, gas extraction and scrubbing required. Specialised training (including BA) for changing cylinders and responding to leaks.	Corrosive liquid – can cause skin burns and eye damage. PPE and training required. Use of incorrect materials in dosing system/lack of maintenance can result in leaks. Can release chlorine gas through off-gassing, heating or exposure to acids.	Very low concentration minimises hazard. Dilution of by-product hydrogen gas required. PPE and training required.	Highly reactive. Strong oxidising agent, can cause skin burns and eye damage. PPE and training required.
Community safety	High risk in event of large-scale gas release.	Minimal risk	Minimal risk	Minimal risk
Environ-mental risk	Gas release unlikely to enter aquatic environment. Risk to wildlife in event of large-scale gas release.	Chlorine is highly toxic to aquatic ecosystems. Spills must be contained.	Chlorine is highly toxic to aquatic ecosystems but reduced risk due to low concentration. Spills must be contained.	Chlorine is highly toxic to aquatic ecosystems. Spills must be contained.

Operability

	Chlorine gas	Sodium hypochlorite - bulk liquid	Sodium hypochlorite - generated on site	Calcium hypochlorite
Complexity	Relatively straightforward and well established.	Relatively straightforward and well established.	High complexity sodium hypochlorite generation system. Dosing and storage systems as for bulk sodium hypochlorite.	Tablet dosing systems low complexity but can be time consuming to operate[2]. Granular and briquette calcium hypochlorite solubilisation and dosing systems more complex, particularly if automated.
Servicing and calibration	Regular inspection and condition assessment required. Specialised servicing and maintenance requirements. Routine servicing and calibration of gas meters required.	Regular inspection and condition assessment required. Regular servicing, maintenance, calibration of dosing pumps and transfer lines.	Specialised servicing and maintenance requirements for sodium hypochlorite generation system. Regular servicing, maintenance, calibration of dosing pumps and transfer lines.	Tablet dosing systems require regular cleaning and maintenance[2]. Regular inspection and cleaning for powder dosing systems. Regular servicing, maintenance, calibration of briquette solubilisation systems, dosing pumps and transfer lines.
Reliability	Reliable with appropriate inspection and maintenance.	Reliable with appropriate inspection and maintenance.	Dosing system reliable with appropriate inspection and maintenance.	Difficult to maintain consistent chlorine residual with "floater" systems[2]. Reliable with appropriate inspection and maintenance. Dosing system blockages can impact on operational reliability.
Attendance / Monitoring	Requires on-line residual chlorine monitoring. Remote monitoring and alarming recommended. Regular operator attendance required.	Requires on-line residual chlorine monitoring. Remote monitoring and alarming recommended. Regular operator attendance required.	Requires on-line residual chlorine monitoring. Remote monitoring and alarming recommended. Regular operator attendance required.	Requires on-line residual chlorine monitoring. Remote monitoring and alarming recommended. Regular operator attendance required.

What are Queensland water service providers doing?

qldwater surveyed its members in April 2018 to determine their current chlorination practices, their views about the benefits or otherwise of those practices, and their plans for the future. The survey asked respondents to rank their current solutions from 1 to 5 with 5 being the most preferred option in terms of overall cost to operate (capital and operational costs), the best solution to manage public health (considering all factors including DBPs and chlorates) and as a safe worker solution (storage and handling).

The 10 responding water service providers (WSPs) ranged in size from very small to very large and the following table summarises their responses.

Five of the responding WSPs use sodium hypochlorite only, one uses chlorine gas only and the remaining four use chlorine gas and hypochlorite. None of the respondents generate sodium hypochlorite on site (there are known installations in Logan, Rockhampton and Burketown).

	WSP description	Chlorination option	Average ranking: overall cost to operate	Average ranking: best solution to manage public health	Average ranking: safe worker solution	Planned changes, timing and reasons
1.	Medium Regional/rural	Sodium hypochlorite 12 sites	2.75	1.75	4.00	Considering chloramination for 4 sites in 2018/19 - DBP control. Favour gas for 4 sites in next asset funding cycle – cost and operational reasons.
2.	Small Remote	Sodium hypochlorite 2 sites	3.00	5.00	4.00	None planned
3.	Extra Large Regional	Sodium hypochlorite 11 sites	4.00	3.00	4.00	Note all sites use UV for primary disinfection.
4.	Small Remote	Chlorine gas 1 site	3.00	2.00	2.00	Investigating hypochlorite or chlorine dioxide for 2019 – safety concerns and ease of handling.
5.	Large Regional/ Rural	Sodium hypochlorite 8 sites	3.71	1.57	4.00	Investigating chlorine gas – longer shelf life, storage / transportation flexibility, reduced chlorate and DBP potential. Timing influenced by adoption of ADWG chlorate health guideline.

Survey results (continued)

5.	(Continued)	Calcium hypochlorite 1 site	4.00	3.00	5.00	Investigating alternative more flexible dosing options.
		Chlorine gas 5 sites	4.00	4.00	3.20	Nil
6.	Medium Regional/ Remote	Sodium hypochlorite 1 site	5.00	4.00	4.00	Nil
		Chlorine gas 2 sites	2.00	4.00	2.00	Nil
7.	Small Remote	Sodium hypochlorite 2 sites	4.00	3.00	4.00	Chlorate issues – preferred reduction option is process optimisation followed by alternative disinfection if unsuccessful.
8.	Medium Rural	Sodium hypochlorite 8 sites	4.00	4.00	4.00	None currently planned. Considering on-site generation in the future to improve chemical purity.
		Chlorine gas 2 sites	4.00	4,00	3.00	Nil
9.	Medium Rural	Sodium hypochlorite 6 sites	4.00	4.33	3.50	Replace chemical storage tanks at 1 site within 2 years. Otherwise nil.
10.	Extra Large Regional	Sodium hypochlorite 3 sites	5.00	3.33	4.33	Considering converting 1 large WTP to chlorine gas – chlorates management.
		Chlorine gas 1 site	5.00	5.00	5.00	Nil

Discussion Points

Shelf-life and stability

It is well understood that the available chlorine in high strength sodium hypochlorite solutions degrades significantly over time, reducing from 13.5% to 10% in about two months at 22°C, and more quickly at higher temperatures[1]. Chlorates form as by-products and the concentration increase is proportionate to the loss of available chlorine. Apart from increased temperatures, things that increase the degradation rate include a pH below 12, impurities such as copper and nickel and exposure to the UV wavelengths in sunlight.

Queensland's small and remote water schemes are highly exposed to the conditions that promote sodium hypochlorite decay and chlorate formation. They commonly have low sodium hypochlorite solution turn-over due to low water production, and experience climatic conditions that can include high daytime temperatures and strong sunlight, but often have to store hypochlorite solution in basic sheds or even in the open, exposed to sunlight and without temperature control.

Extreme weather events like cyclones and flooding may limit or cut road access for deliveries, and for remote areas or those with poor road conditions, deliveries can be infrequent and expensive. As a result, these utilities need to hold large stocks of hypochlorite solution to ensure continuity of disinfection and the supply of safe drinking water. Taken with the often small volumes of hypochlorite solution used, this leads to extended storage time and increased loss of solution strength and chlorate formation.

These issues are discussed in ***qldwater***'s Chlorate Fact Sheet, available from the ***qldwater*** website.

The water safety impacts are two-fold; one being reduced disinfection efficiency due to reduced chlorine strength. This increases the risk of microbial contamination from incomplete disinfection and makes it more difficult to maintain a disinfectant residual throughout the reticulation system. The other potential health impact is from chlorates in the drinking water.

As the sodium hypochlorite solution degrades, the dose rate must be increased to achieve the required chlorine dose, which in-turn increases the concentration of chlorate in the drinking water and the commensurate health risk.

There are ways of reducing the impacts of sodium hypochlorite's shelf life issues, all of which have advantages and disadvantages. How these costs compare with the costs of converting to and operating chlorine gas systems or calcium hypochlorite dosing systems will vary on a site by site basis.

1. Minimise storage time by optimising delivery frequency and volume. This strategy is most effective for large WTPs with good road access, and can be difficult to implement for small and/or remote schemes. Transport costs will probably be higher for more frequent, smaller deliveries, and higher than for delivering chlorine gas. Ensure contract documents reflect delivery turn-around and frequency requirements.
2. Minimise as-supplied chlorate concentrations and decay-increasing impurities by specifying compliance with the American Water Works Association Standard for Hypochlorites ANSI/AWWA B300 or similar. This is the common practice among larger Queensland water utilities, meaning that the product should already comply and costs should not increase.
3. Minimise degradation by diluting sodium hypochlorite to less than 10% available chlorine for storage. Negatives of this approach include the costs of providing increased on-site storage and the higher capacity dosing systems needed to dose the diluted solution.
4. Consider on-site sodium hypochlorite generation, which produces a much more stable low strength solution and minimises on-site hypochlorite storage requirements. These systems are significantly more expensive to build and require specialised maintenance, but the only required bulk chemical is salt, which is stable and can be stored for long periods.

Another obvious alternative is to convert to chlorine gas disinfection. Chlorine gas does not degrade over time, is less expensive per kg chlorine, and is generally less expensive to deliver.

However, chlorine gas fittings and pipework are known to suffer corrosion problems, especially under high temperature and humidity conditions, and operators require a higher level of knowledge and training for safe operation. A common example is the corrosion of brass pigtail fittings on chlorine gas manifolds, which occurs when water condenses in the fittings and, in the presence of chlorine gas, forms hydrochloric acid which leads to brass dezincification[3]. The condensation can be atmospheric water which enters the fittings during cylinder changeover or storage, or impurity water present in the chlorine. External corrosion occurs when imperfect seals allow small chlorine gas leaks which again interact with atmospheric condensation, particularly under high humidity conditions.

Chlorine gas deliveries are likely to be subject to similar availability and access restrictions as liquid sodium hypochlorite for remote locations and these need to be addressed in contract documentation.

Automated calcium hypochlorite solubilisation and dosing systems are increasingly available and may be an effective solution for some sites. Calcium hypochlorite offers improved shelf life, reduced risk of chlorate formation and possibly reduced chemical costs compared to sodium hypochlorite, although availability and access restrictions may also apply for remote locations.

Operational experience suggests that calcium hypochlorite solubilisation and dosing systems may experience blockage issues and require frequent operator intervention and maintenance to ensure reliable operation.

Chlorine gas vs sodium hypochlorite vs calcium hypochlorite – the safety issues

Much of the discussion about the relative merits of chlorine gas, sodium hypochlorite and calcium hypochlorite for water and wastewater disinfection is about operator and public safety. Some of the common issues are:

Which is the most dangerous?

The simple answer is that all chlorine based disinfection chemicals are hazardous and are potentially dangerous. Chlorine gas poses the greater risk because of the much higher consequences of exposure, while sodium hypochlorite solution and solid calcium hypochlorite are generally viewed as less dangerous.

The likelihood of an incident with sodium hypochlorite solution may he greater and it can cause serious burns, is highly corrosive and has the potential to release toxic chlorine gas under some conditions. However, the consequences are less significant than for a chlorine gas release and are usually assed as a lower overall risk.

Calcium hypochlorite poses similar handling and exposure safety risks to sodium hypochlorite solution, with additional storage risks due to its extreme reactivity in the presence of water and organic materials.

Which causes the most safety incidents?

Despite its toxicity, examples of injury or death caused by exposure to chlorine gas are very rare in Australia, which is largely attributable to more careful management often driven by the high degree of regulation that applies to it. On the other hand, the Australian press regularly carries reports of injury or environmental damage caused by sodium hypochlorite incidents. The reported incidents are often associated with swimming pools and result from poor storage and handling practices, poor maintenance and lack of training and procedures. The Australian water industry, with its focus on safety, training and procedures, reports few significant sodium hypochlorite related incidents.

The introduction of new calcium hypochlorite dosing technologies in the water industry is a relatively new development and a clear picture of practical safety implications is yet to emerge.

How can I avoid chlorination safety incidents?

The principles for safely operating chlorine gas, sodium hypochlorite or calcium hypochlorite based disinfection systems are essentially the same:

- Identify the hazards, and assess and manage the risks.
- Ensure that the chlorination facility complies with the appropriate standards - *AS/NZS 2927:2001 The storage and handling of liquefied chlorine gas* for chlorine gas, *AS 3780-2008 The storage and handling of corrosive substances* for sodium hypochlorite solution and calcium hypochlorite, and the ADG code.
- Document safe working procedures, and identify, supply and **maintain** the correct PPE. Don't forget that BA units especially need regular maintenance and testing.
- Have a documented and enforced inspection, maintenance and calibration program.
- Train, train, train. All staff operating or maintaining chlorination systems must understand the operating principles, the hazards and risks, and how to manage them. The training must be regularly reinforced. Chlorine gas systems require a higher level of training and knowledge. Ensure that support and advice are readily available in the field and that staff know how to access them.

How important are these things to Queensland's WSPs?

Section 2.5 shows the compiled responses to ***qldwater***'s chlorination survey questionnaire. These responses demonstrate Queensland WSPs' understanding of the issues, real-world opinions, experiences and operational and planning responses in relation to the issues discussed above, and also to the issue of costs.
To summarise:

Shelf life and stability

Concerns about sodium hypochlorite solution degradation and chlorate formation are clearly recognised and play a significant role in WSPs' decision making about disinfection options. However, a significant proportion of the survey respondents were possibly not aware of the concerns or, probably more likely, did not consider them to outweigh the perceived advantages of sodium hypochlorite over chlorine gas.

- Of the 9 respondents employing sodium hypochlorite or calcium hypochlorite at 1 or more of their sites, 5 ranked it at 3.33 or less out of 5 as the best solution to managing public health, primarily due to the risk of chlorate formation. 4 of the 5 WSPs were considering changing to chlorine gas to reduce chlorates and/or DBPs, although 1 favoured optimising sodium hypochlorite

dosing as a first option. 1 was considering chloramination for some sites to manage DBP formation and reduce costs.

- The remaining 4 sodium hypochlorite users ranked it as 4 out of 5 or better from a public health perspective and had no plans to change to an alternative disinfectant. It is unclear whether these WSPs considered themselves to be effectively managing the shelf-life and chlorate issues, felt they were outweighed by other considerations, or did not consider them significant.
- One small remote WSP ranked chlorine gas at 2 out of 5 for public health, but did not indicate whether the ranking was due to drinking water quality concerns or risks to the safety of the surrounding community.

The safety issues

Overall, the survey respondents rated chlorine gas as posing the greater risks to worker safety.

- 8 of the 9 respondents using sodium or calcium hypochlorite ranked it at 4 out of 5 or above as a safe worker solution. The other's overall ranking of 3.5 encompassed individual plant rankings ranging from 2 to 5, perhaps reflecting a wide range in the age and quality of installations. This WSP did not however indicate any plan to move away from sodium hypochlorite disinfection.
- Of the 5 survey respondents using chlorine gas disinfection, all but 1 ranked it as 3.22 or lower, with 2 giving a ranking of 2. The 5th however ranked chlorine as 5 out of 5. This ranking applied to a large WTP operated by a very large WSP and may reflect a greater capacity and confidence in managing the safety issues.
- 1 small remote WSP currently using chlorine gas indicated that worker safety was a major driver in considering sodium hypochlorite or chlorine dioxide as future disinfection options.
- 3 of the 4 WSPs using both sodium hypochlorite and chlorine gas gave gas a lower worker safety ranking. The 4th however gave its single chlorine gas facility a ranking of 5, along with 2 of its 3 sodium hypochlorite installations.

3. Cost

The ***qldwater*** survey questionnaire asked respondents to rank overall operating costs, including capital and operational costs. The questionnaire did not seek a breakdown of costs and so it is not possible to draw conclusions about the relative contributions from chemicals, transport, maintenance and safety systems costs. In general, the rankings appeared to be more impacted by WSP location and transport factors than by the choice of chlorination chemical.

- The lowest sodium hypochlorite cost rankings were in the range of 2 to 3 and were assigned by 2 WSPs that were impacted by long transport distances and/or transport access difficulties. A third relatively large WSP servicing widely separated schemes across a large inland area also assigned a relatively low average ranking of 3.71. The remaining 6 sodium hypochlorite users assigned cost rankings of 4 or 5.
- 1 small remote WSP ranked chlorine gas cost at 3 out of 5, while another medium regional/ remote WSP assigned a ranking of 2. Cost rankings for the remaining chlorine gas users were 4 or 5.
- 3 of the 4 WSPs using both hypochlorite and chlorine gas assigned them the same or similar cost rankings. The regional/ remote WSP mentioned above gave sodium hypochlorite a cost ranking of 5 compared to its low ranking of 2 for chlorine gas.

Case Studies

Round Mountain Reservoir

The 20 ML Round Mountain Reservoir provides drinking water to a key growth area South-West of Logan City. It receives bulk water with chloramine as the residual disinfectant. The water age in the network is longer than desirable, resulting in low residual chloramine, in the absence of an activity to boost that residual.

Network modelling indicated that free chlorine dosing at the Round Mountain site would provide the most significant improvement in water quality across the zone. The Logan Water Infrastructure Alliance investigated three options (and a series of sub-options) for chlorination at the reservoir, which carries a set of specific challenges including no access to mains power, and an unsealed access road.

Broadly, the options were:

1. Sodium hypochlorite – with 14 days storage, use of the existing road (vs rehabilitation of the road)
2. Electro-chlorination – with 14 days brine storage and rehabilitation of the road, 28 days brine storage, and 14 days with extra salt storage on-site
3. Calcium hypochlorite – with 14 days storage and rehabilitation of the road.

The chosen option of electro-chlorination with 28 days brine storage ultimately met the desired criteria of being cost-effective, reliable at critical times of the year, and delivering water quality compliance.

The electro-chlorinator:

- Removed the need to have hazardous chemical delivered to the site on a regular basis;
- Eliminated the requirement to upgrade the road to manage deliveries in adverse weather conditions;
- Produces low strength (<1%) hypochlorite which is not classified as a hazardous material; and
- Leads to low rates of chemical degradation in comparison to standard 12% strength hypochlorite.

In this instance, calcium hypochlorite dosing solutions were discounted because of a relatively higher capital and operating cost, additional safe storage requirements (high volumes), and a requirement for higher operator input. The project manager noted that there would be other, smaller scale applications where the calcium hypochlorite solutions would be viable.

Council was also able to develop an on-site power generation solution through 323 solar panels delivering 87 kWh, combined with a 95 kWh Tesla battery. The electrolysers only operate to create brine when there is solar power available, the battery provides dosing capability when there is no solar power available, as well as three days backup power for dosing and instrumentation.

The system overall has a range of extra features to support site safety, as well as to optimise brine production and minimise maintenance, including hydrogen sensors and alarms, chillers and water softeners to reduce calcification. At full production, the system uses 143 kg of food grade salt a day. It can store 28 days of brine, with 4 weeks' reserve of salt on site in 600 kg bags.

Challenges in implementing gas chlorination and fluoridation in six remote indigenous communities of the Northern Territory

This case study describes the implementation of gas chlorination in six remote Northern Territory communities. It illustrates the measures required to achieve safe operation of gas based systems under conditions similar to those faced by many small and/or remote Queensland service providers. A significant difference to the remote Queensland scenario is the existence of a single overarching organisation with high level technical and professional resources.

Northern Territory Power and Water Corporation's Remote Operations provides power, water and sewerage services to 20 Territory Growth Towns and 52 remote communities. The communities are sparsely located across the Northern Territory and have populations of 3000 or fewer. The special challenges these communities face in providing a safe and reliable drinking water supply include remoteness with long distances from support centres, high levels of climate variability and limited local technical capacity and expertise to operate and maintain drinking water systems.

The daily operation of each community's power, water and sewerage services is undertaken by a dedicated Essential Services Officer (ESO), whose education level can range from minimal literacy to trade-qualified.

This case study considers the challenges associated with designing, delivering and commissioning upgraded water chlorination and fluoridation plants for six Territory Growth Towns. Three of the six communities are accessible by sea or air only, and the remaining three also have a level of road access only during the three to four months of the dry season.

All six chlorination facilities had historically experienced problems with the existing sodium hypochlorite drinking water chlorination systems, including degradation due to long storage (circa 3 months) of the chemical under hot and humid conditions, chlorate formation and safety concerns around handling and transport of the sodium hypochlorite due to inadequate design. Chlorine gas disinfection was identified as the most appropriate upgrade alternative to overcome the existing issues. The source paper does not describe the criteria used for assessing alternatives or discuss the relative capital and operating costs.

Two standard chlorine systems were developed to comply with AS2927:2001 Storage and handling of liquefied chlorine gas; the first designed around a single annual chlorine delivery and using a 920 kg drum with a 70 kg cylinder as backup to cover the period between ordering and delivery of a new drum. The second system, for use when adequate development buffers could not be achieved, utilised 2 x 70 kg cylinders with one cylinder expected to last about one month and necessitating significantly more frequent deliveries. Pre-cast moulded concrete buildings were specified to house the chlorination systems.

The combined chlorination/fluoridation plants were PLC-controlled with an operator interface panel incorporated for day-to-day operation. The remote locations necessitated the provision of in-built automated safety features. Chlorine storage rooms were fitted with 2 x chlorine gas detectors triggered to give an audible alarm at 2 ppm and automated shutdown and external visible alarms at 5 ppm. The systems also shut down when an extended power outage was experienced.

The remote locations of the WTPs means that the evacuation of surrounding areas in the event of a significant leak would be problematic, leading to the adoption of very conservative buffer distances.

Significantly, when a chlorine leak alarm is generated the ESO is required to notify a Power and Water Corporation officer and evacuate the site. The Power and Water Corporation Officer is responsible for remedial action. In a Queensland context, operators of small and remote WTPs do not generally have this level of off-site support and would usually have to address the problems themselves.

At the time of the paper's publication, all systems were covered by a six month maintenance contract with an external provider, supported by ESOs undertaking regular inspections to identify wear and tear or abnormalities.

Also at the time of publication of the source paper, Power and Water had yet to identify the most effective methods for delivering chlorine drums to the remote communities.

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