WATER CORPORATION

Assets Planning and Delivery Group
Engineering

DESIGN STANDARD DS 78

Chemical Dosing

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REVISION 0

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FOREWORD

The intent of Design Standards is to specify requirements that assure effective design and delivery of fit for purpose Water Corporation infrastructure assets for best whole-of-life value with least risk to Corporation service standards and safety. Design standards are also intended to promote uniformity of approach by asset designers, drafters and constructors to the design, construction, commissioning and delivery of water infrastructure and to the compatibility of new infrastructure with existing like infrastructure.

Design Standards draw on the asset design, management and field operational experience gained and documented by the Corporation and by the water industry generally over time. They are intended for application by Corporation staff, designers, constructors and land developers to the planning, design, construction and commissioning of Corporation infrastructure including water services provided by land developers for takeover by the Corporation.

Nothing in this Design Standard diminishes the responsibility of designers and constructors for applying the requirements of Western Australia's Work Health and Safety (General) Regulations 2022 to the delivery of Corporation assets. Information on these statutory requirements may be viewed at the following web site location:

Overview of Western Australia’s Work Health and Safety (General) Regulations 2022 (dmirs.wa.gov.au)

Enquiries relating to the technical content of a Design Standard should be directed to the Senior Principal Engineer - Water Treatment, Engineering. Future Design Standard changes, if any, will be issued to registered Design Standard users as and when published.

Head of Engineering

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The revision status of this standard is shown section by section below:

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Chemical Dosing

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1 INTRODUCTION

Chemicals are dosed as part of a treatment process to achieve a water quality outcome. The effectiveness and efficiency of chemical dosing depends on:

- the nature (properties) of the chemical;
- the mixing of the chemical into the recipient water main; and
- the control of the dose rate.

Issues commonly arise when designers:

- do not adequately consider the properties of the chemical being dosed;
- do not consider possible reactions;
- provide insufficient mixing;
- provide poor sampling; or
- design systems that are inherently difficult to control.

1.1 Purpose

This design standard, DS78, describes the key process issues associated with dosing and mixing of chemicals into water.

It concentrates on the issues to be considered rather than recommending solutions for all chemicals, although specific examples are provided for some chemicals.

1.2 Scope

This standard covers the design of systems for the dosing and mixing of chemicals into water flowing within a pipe or channel. It attempts to generally cover all aspects that process designers need to consider when designing such systems. It also covers many aspects that are relevant to piping, mechanical, instrumentation and controls designers.

Specific considerations and common issues are also given for many chemicals, with a focus on design aspects where the Water Corporation commonly experiences problems. This standard also provides a rationale for the selection of an appropriate mixing regime for the chemical dosing system, taking into consideration the following:

- chemical properties;
- mixing; and
- system design (i.e. piping configuration, process controls).

DS78 does not cover the upstream bulk delivery and storage of chemicals, which is mostly covered by other Water Corporation design standards (refer to DS79 and to the design standards for specific chemicals).

1.3 Standards and Regulations

1.3.1 Water Corporation Standards

Reference is made to the following Water Corporation standards:

DS 31-01	Pipework– Mechanical
DS 31-02	Valves & Appurtenances - Mechanical

DS 33	Water Treatment Plants – Mechanical
DS 34	Wastewater Treatment Plants – Mechanical
DS 40-08	Chemical Dosing Control
DS 40-09	Field Instrumentation
DS 70 set	Chlorine Standards
DS 71 set	Fluorosilicic Acid (FSA) Standards
DS 72 set	Lime Standards
DS 73 set	Sodium Hypochlorite Standards
DS 79	Design of Chemical Systems – Legislative Requirements and General Principles
DS 79-02	Emergency Safety Showers & Eyewash Stations
DS 79-03	Chemical Barrier Protection
DS 79-04	Signage, Labelling & Markers
DS 81	Process Engineering

1.3.1.1 Standard Designs

Planset/Drawing	***Description***
JZ39-2-1 to 4	Sampling and Dosing Spears – standard drawings
EO28-01-22	Chlorine Dosing Spear – standard drawing
LP12	Tank Level Instrumentation – Standard & Example drawings

The Water Corporation has standard designs for chlorine dosing and sampling systems – refer to the EO28 drawings planset.

1.3.2 Australian Standards

AS 3780	Storage and Handling of Corrosive Substances

1.3.3 Regulations

Dangerous Goods Safety Act 2004

Dangerous Goods Safety (Storage & Handling of Non-Explosives) Regulations 2007

Department of Health Fluoridation of Public Water Supply Act 1966

Work Health Safety Act 2020

Work Health Safety (General) Regulations 2022

1.4 Abbreviations

CFD	Computational Fluid Dynamics
CIP	Clean-In-Place
CoV	Coefficient of Variation
D	Diameter

DN	Nominal Diameter (Diameter Nominal)
FSA	Fluorosilicic Acid
IFM	Integrated Flow Monitoring
O&M	Operations & Maintenance
ORP	Oxidation-Reduction Potential
NPSH	Net Positive Suction Head
PAC	Powdered Activated Carbon
P&IDs	Piping & Instrumentation Diagrams
RO	Reverse Osmosis
SCADA	Supervisory Control and Data Acquisition
VIV	Vortex Induced Vibration

2 CHEMICAL PROPERTIES

Many reaction issues and hazards[1] can arise when a chemical and water are mixed, whether this is with batching water, dilution water, the receiving water, or the disposal of waste streams containing chemicals (especially reactions between waste streams containing different chemicals). The properties of the chemical being dosed (refer to Table 2-1) must be considered in the design of chemical dosing systems. Some of these conditions will be based on information obtained from the Mass and Component balance in the process design (refer to process engineering design standard DS81), and other conditions - such as vapour pressure and heat rise during reaction - should be used to verify/update the Mass and Component balance.

Table 2-1 – Chemical Properties and Issues

Chemical Property and Associated Issues	**Applicable Area / Standard**	
	Dosing (DS 78)	**Bulk Storage & Feeding**
Liquid Density	X	X
Viscosity	X	X
Vapour pressure and fuming	vapour locking	X
Temperature and changes of phase:		
Freezing / Crystallisation	X	X
Boiling	X	X
Chemical reactions and hazards:		
Heat Rise	X	batching
Foaming		X
Explosion Hazards	hydrogen; ammonia	X
Precipitation / Scaling	X	X
Reactions with dilution water	X	batching
Flammability (e.g. ethanol)		X
Deposition (including scaling & loss of suspension)	X	X
Chemical degradation (time-related e.g. in the storage, long dosing lines, etc.)	X	X
Decomposition (unintended events, by-products)	X	X
Corrosiveness and Material Degradation	X	X
Human Health Risk	X	X
Environmental Risks	X	X
Start-up, shut-down & down-time implications	X	X

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[1] In addition to chemical reactions, note that biological activity may cause problems such as loss of residual disinfectant concentration due to denitrification in chloraminated systems (or potential benefits such as biological degradation of THMs) and may cause hazards such as growth of pathogenic organisms.

Chemical Property and Associated Issues	Applicable Area / Standard	
	Dosing (DS 78)	Bulk Storage & Feeding
Other O&M considerations e.g. availability, remoteness, transport cost (related to delivered concentration).	X	X

2.1 Physical Properties

Every treatment chemical has physical properties that influence the design of the chemical dosing system such as viscosity, vapour pressure, freezing point, boiling point and others. This section outlines common issues associated with each property.

2.1.1 Density

The range of “specific gravity” values (ratio of the chemical solution density to density of water) for liquid chemicals in water treatment applications is in the range of ~0.9 (25% w/w ammonium hydroxide) to ~1.84 (98% w/w sulphuric acid). Density differences between the injected chemical solution and the recipient main water flow may impact on the required mixing length within which flow turbulence will disperse the chemical evenly across the entire cross-sectional area of the water main. Higher density difference will require greater mixing length.

Chemical density also impacts several aspects of the chemical storage area design including, but not limited to storage tank design and pressure-transducer tank level instrument calibration. Refer to DS79 for further details.

2.1.2 Viscosity

Chemicals such as polymers, sodium aluminate and sodium silicate are highly viscous. For some fluids, viscosity significantly increases at lower temperatures. Viscous fluids are often diluted before injection into the main fluid flow. Even with dilution, viscosity differences between the injected fluid and the main water flow may impact on mixing.

High viscosity fluids will also result in higher friction losses in dosing pump suction and discharge piping which must be accounted for by the designer. The selection and specification of dosing pumps may also differ for high viscosity chemicals. Lower operating speeds and the inclusion of spring return check valves in the dosing pump head is common. Dosing pump vendors should be consulted, or a comprehensive procurement datasheet prepared for the dosing pumps.

2.1.3 Vapour pressure and fuming

Fluids with high vapour pressure are more volatile and may release potentially hazardous fumes. Although sodium hypochlorite can release chlorine fumes, vapour problems impacting dosing system operation are instead due to the oxygen produced when sodium hypochlorite degrades into sodium chloride, sodium chlorate and oxygen. The oxygen bubbles generated can impact dosing pump performance which is seen either as reduced output or “vapour-locking” which results in complete loss of dosing. Careful design of the dosing pump suction and delivery piping - using the principles detailed in Sodium Hypochlorite design standard DS73 - can practically eliminate vapour-locking and gassing-off problems when dealing with such chemicals.

While vapour pressure needs to be accounted for in net positive suction head (NPSH) calculations, this is not normally a design consideration once the chemical has been dosed into solution water (which produces a dilute solution that is conveyed to the dose point in closed conduits under pressure). Fuming risk may still need to be considered in the context of any leaks and confined spaces where leaks and associated fumes may accumulate.

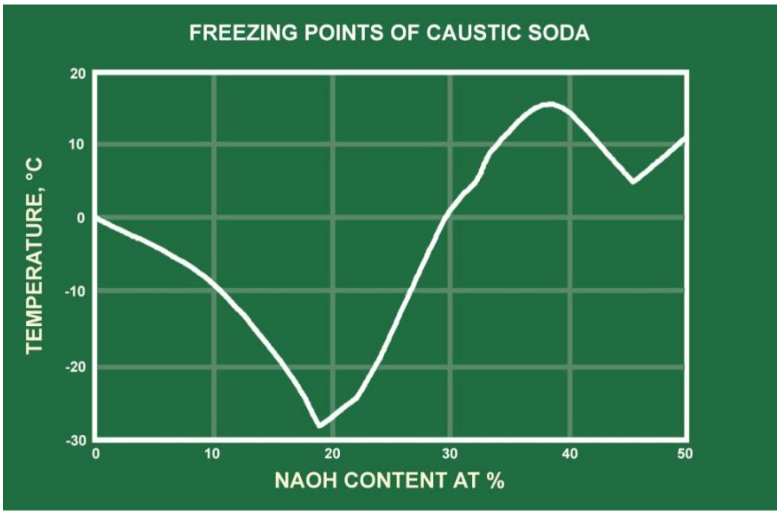
Some chemicals have small concentrations of highly volatile impurities that will lead to fuming, though the vapour pressure of the principal chemical itself is not high.

Chemicals that may have high vapour pressure and/or are fuming include sodium hypochlorite, fluorosilicic acid, hydrochloric acid, ammonium hydroxide and sodium bi-sulphite.

2.1.4 Temperature and Changes of Phase

Freezing/ Crystallisation

Low temperature may result in crystallisation/ freezing either in the storage tank or in the dosing pipework. Examples include 50% w/w sodium hydroxide and 35-40% w/w sodium bisulphate whose freezing points are above 0ºC at certain concentrations. This is illustrated in Figure 2-1 below.



Source: https://www.protank.com/sodium-hydroxide

Figure 2-1 – NaOH Freezing Point by % Concentration versus Temperature (ºC)

Freezing risks may be lowered through several actions:

- By having the chemical delivered in more dilute form, or by locating tanks and feed system indoors in a controlled or less variable temperature environment.
- For tanks – immersion heaters, heat tracing, recirculation systems, lagging (insulating) the tank.
- For pipes – heat tracing, lagging, running in below ground trenches.
- Dilution as soon as possible (but consider risk of scaling – refer section 2.2.5).
- For vapourisation from gas cylinders, strategies include ensuring sufficient cylinders on-line based on the most onerous design condition (maximum gas draw rate in minimum ambient temperature), providing heating on the cylinder outlet valve, or liquid draw-off to evaporators (heat exchangers).

To avoid freezing risk in pipework, Water Corporation's preferred approach for 50% w/w Caustic Soda is to dilute as soon as possible after dose pumps, unless dosing lines are very short, in which case heat tracing is acceptable.

Boiling

Some chemicals have lower boiling points than water. For example, 25% w/w ammonium hydroxide has a boiling point of approximately 40ºC. Potential boiling, particularly in non-operational lines, may be identified as a high risk or require high piping capital cost to withstand these deleterious effects or have risks that could potentially be mitigated by dilution.

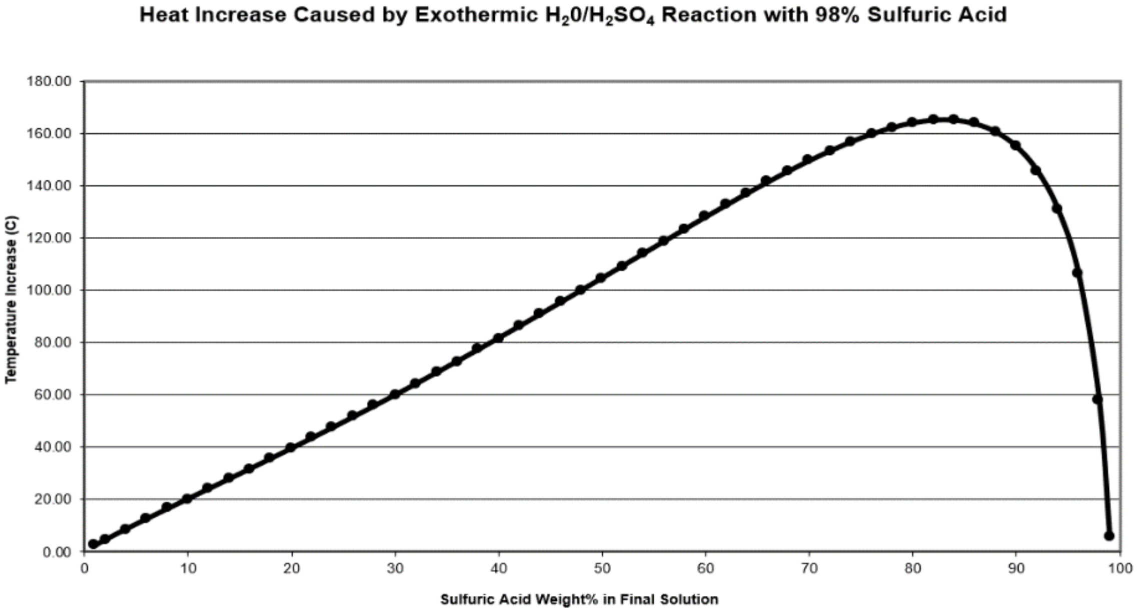
2.2 Chemical Reactions

This section outlines the various chemical reactions, hazards and design issues to be considered for typical water treatment chemicals such as foaming, scaling, explosion, heat production and decomposition. Note that chemical reactions may occur when chemical is added to the dilution water and when added to the recipient water main.

Note that chemical storage area separation and segregation requirements are covered in DS79 and not repeated here.

2.2.1 Heat Rise

Some concentrated chemicals react exothermically (release heat) when mixed with water e.g. 98% w/w sulphuric acid will exceed boiling point on mixing with water unless dilution is to below 40% w/w under typical fluid temperatures. This is illustrated in Figure 2-2.



Source: https://www.chemical-supermarket.com/ Acids/

Figure 2-2 – Heat Rise for Sulphuric Acid

For other chemicals, which are delivered at much lower concentration (e.g. 30-50% w/w), a heat rise of 30° to 40°C can be expected at low dilution rates. Dilution at 20:1 by weight for 98% w/w sulphuric acid and at 5:1 by weight for most other chemicals should limit heat rise to < 10°C in the fully mixed fluid. Typical minimum dilution that Water Corporation adopts for all[2] chemicals is to a 20:1 ratio by weight. Dilution water flow rate is normally set at commissioning and determined on a 20: 1 ratio with the maximum flow rate of the dosed chemical.

The designer must consider:

- design of mixing / mixing tees especially for sulphuric acid to fully mix the chemical with the dilution water. These mixing devices must be rated for the highest temperatures expected in areas of incomplete mixing (and material selection must be suited to the corrosivity of the incompletely mixed chemical);

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[2] Although not related to heat rise, much greater dilution is commonly used for polyelectrolyte as discussed in sections 2.2.7, 3.1 and 3.3.6.

- design to minimise reactions that might be ongoing after a chemical system is shutdown i.e. where there are pockets of concentrated chemical and adjacent pockets of water that continue to diffuse and dilute, thereby continuing to increase in temperature in the absence of flow. Materials must be selected for the worst temperature and corrosion conditions;
- diffusion of water back into chemical lines, and vice-versa when the plant is shutdown;
- increased local corrosion rates due to elevated temperature;
- pipe pressure de-rating due to increased local temperature in dilution zones (since temperature rise for partly diluted chemical may be much higher than once fully mixed);
- downstream pipework may in any case need to be de-rated for increased temperature; and
- the maximum temperature that the service water may be prior to addition of chemical i.e. add the temperature rise to the service water temperature to determine the design temperature of the solution line.

2.2.2 Foaming

Foaming is not an issue in closed dosing lines and receiving water conduits and is not a design consideration for DS78.

2.2.3 Explosion Hazards

Consider whether flammable/explosive gases may be formed (e.g. hydrogen during electro-chlorination and from reaction of acids with solid metals) or released (e.g. ammonia). The designer should consider whether discharge of vapour from a vent or overflow pipe or a spillage within an enclosed space/room (or discharge into a tank) may result in a vapour concentration which is potentially explosive.

Explosion hazards are also associated with delivery and batching from bulk powder (e.g. dry powdered activated carbon, PAC) and with enclosed headspaces in storage vessels (e.g. ammonium hydroxide), rather than in the dosing systems and is therefore not specifically covered in DS78.

2.2.4 Toxic Gases

Vapour from chlorine or sodium hypochlorite solution can be extremely dangerous in an enclosed room. Evolution of chlorine gas (due to reduced solubility) may also occur when solutions containing sodium hypochlorite are reduced in pH (such as in CIP neutralisation).

2.2.5 Precipitation/Scaling

The risk of precipitation and scaling when dosing chemicals is exacerbated by high pH and/or by high hardness. Scaling issues typically occur in the dilution zones where chemical is mixed with water. If the solubility product for any sparingly soluble salt (e.g. calcium carbonate) is exceeded anywhere within the mixing zone, then scale can form on exposed surfaces. This may occur in the solution line, plus clog valves or impact their seating effectiveness, and is common on chemical dosing spears.

Calcium carbonate is the most common scale formed. Less common scales include calcium fluoride, calcium sulphate, magnesium fluoride and metal silicate scales. Some scales such as calcium carbonate are reversible using acid solutions, while others such as calcium sulphate and metal silicate scaling are almost irreversible. In waters with high silica content and with traces of metal ions, very hard scales containing silica (e.g. magnesium silicate) can form when dosing alkaline chemicals.

Chemicals that can exhibit scaling issues are outlined in Table 2-2.

Table 2-2 – Chemicals with Scaling Issues

	Scaling risk associated with dilution water containing		Main Problem Areas		
Chemical	**Hardness**	**Alkalinity / CO_2**	**Dilution point**	**Diluted (dosing) line**	**Injection point**
Lime slurry		X	X	X	X
Lime water		X	N/A	N/A	
Calcium hypochlorite		X	X		
Sodium hydroxide	X		X	X	X
Sodium carbonate	X			X	X
Sodium Fluoride	X		X		
Fluorosilicic Acid	X		X		
Sodium hypochlorite	X		X	X	X
Ammonium hydroxide	X		X	X	X

For coagulants, if water is added for dilution, early coagulation can occur due to impurities in the dilution water (refer to section 2.2.9). This results in the formation of hydroxide precipitates[3] within the dosing line as well as loss of coagulant efficiency. These problems are worse with raw water, treated effluent and highly alkaline water. Refer to section 3.3.5 for guidance on coagulant dilution.

> *Where the addition of dilution water has potential to increase precipitation and scaling risks, it should ideally be avoided or delayed if possible.*

Chemicals which raise pH may be at risk of scale deposition in the dose line and/or clogging the dosing spear. Mitigation strategies to consider include:

Prevention strategies

- using a different process or different chemical;
- use of softened water for chemical solution make-up (e.g. for sodium fluoride saturator systems) and/or dilution/carrier water (e.g. for ammonia gas dosing);
- specifically in RO desalination plants, the permeate water may be suitably soft to use as process water;
- for sites with Calgon® dosing, dose chemical into the Calgon® line, subject to testing to confirm that this will suppress scale formation (boiling test) and not impact the treatment outcome of either Calgon® or the dosed chemical;

Minimisation strategies

- dosing neat chemical, which avoids scale in a solution line;
- reduce length of solution line that is vulnerable to scale formation by delaying addition of the chemical to dilution water till close to the injection point, or avoiding entirely (i.e. dosing neat chemical);
- reduce scale adhesion by use of polyethylene dose lines and HDPE coated dosing spears which may significantly reduce scaling (at least calcium carbonate scaling);
- assess scaling potential formation by calculating solubilities of precipitation products when dosing chemicals in waters with high likelihood or history of scaling. This will inform decision making on order, sequence and mixing requirements;

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[3] Metal hydroxides may also form, which lower pH resulting in increased chemical demand.

- order of dosing chemicals, so that pH and concentration of potentially scale-forming reactants is minimised at the point of dosing;

Management strategies

- providing duplicate dosing lines and injection spears, the latter being retractable to enable removal for cleaning. If feasible, the pipework section holding the dosing spear should be removable to allow cleaning and removal of scale when required. If the rate of scaling is high, then consider whether automatic de-scaling and rotation of the duty and standby dosing lines is required. Considerations for justification of automating de-scaling should include:
    - expected de-scaling frequency and duration of de-scaling maintenance;
    - remoteness of site / operator availability for de-scaling / Regional preference;
    - reliability of de-scale operation;
    - whole of life cost advantage from minimising staff levels;
    - scope to optimise chemical usage;
    - safety aspect from minimising contact with chemicals through automatic operation;
    - cost and complexity of automation; and
    - ease of access to dosing lines to allow replacement.
- if there is a parallel low pH (acidic) solution being dosed, then consider opportunistically switching the chemical dosing lines to dissolve the scale – for example chlorine gas solution, hydrochloric acid and carbonic acid (dissolved carbon dioxide) may be considered for this purpose. Potential reactions of different chemicals must be reviewed so that no adverse effects occur when switching chemicals - for example
    - release of chlorine fumes – acid with sodium hypochlorite; and
    - using sulphuric acid for cleaning calcium scales may result in formation of the more intractable gypsum scale (calcium sulphate). This risk can be assessed based on whether pH and concentrations of (potential) reactants achieved during acid cleaning has a significant precipitation potential of calcium sulphate.
- an alternative acidic cleaning system is to use a dedicated citric acid CIP system. This must consider the effect of mixing potentially incompatible chemicals and the consequent risk to materials and safety;
- using flexible hose for dosing lines so that the scale can be broken up, and use quick disconnect couplings for inter-changeability. Consider whether this is practical/economic/acceptable to Operations; and
- pigging provision on large systems. Consider whether this will be effective based on likely hardness of scale.

These strategies may have cost and/or operational consequences that need to be considered.

2.2.6 Deposition

Fluids that can deposit solids in water treatment applications are those which contain undissolved solids and/or contain inert/ non-soluble particulate matter i.e. typically slurries. Common slurries are lime slurry / milk of lime (whether sourced from hydrated lime, quick lime or lime putty) and powdered activated carbon (PAC). The various forms of available lime in WA and their specific impurities and design considerations are discussed in DS 72-01.

Deposition of solids should not be confused with scaling. Deposition problems occur when there are low pipeline velocities and on shutdown. Control of deposition is usually achieved by maintaining adequate velocities and piping design, incorporating features such as:

- minimising length;
- avoiding sharp radius bends or elbows;
- avoiding vertical legs especially for intermittent flows;

- using hose, especially where the material is also scale forming;
- maintaining high velocities (1 to 2m/s desirable), including use of recirculation ring mains if necessary, to keep velocities up at all times; and
- providing flushing connections and/or automated flushing of systems which operate intermittently.

2.2.7 Chemical degradation

Some chemicals degrade (lose effectiveness) over time. This may be caused or exacerbated by storage at elevated temperatures, storage design (e.g. allowing high liquid-air diffusion of active ingredient) or fluid mixing.

2.2.7.1 Polyelectrolyte

The more dilute a polymer (polyelectrolyte) is, the shorter the shelf life (typical shelf life at 0.05% w/w is 1-2 days, and at 0.25% w/w is up to about a week). Consequently, systems with short shelf life which operate intermittently should automatically be flushed of polymer before shutdown (i.e. for long pauses in operation that will result in the polymer age exceeding 1 day). This is potentially an issue for polymers with relatively long dosing lines because, due to their high viscosity, dosing pipeline velocities are low and detention times and relative volumes are correspondingly high. Dilution water in this case is usually a benefit by reducing viscosity, increasing velocity and facilitates automatic flushing on pipeline shutdown.

Some polymers lose effectiveness when diluted due to chlorine disruption of polymer chains.

2.2.7.2 Sodium hypochlorite

Sodium hypochlorite naturally degrades forming chlorate (an undesirable disinfection by-product) and releasing oxygen gas that may cause gas-locking in the dosing pump or pipework. The degradation rate is proportional to temperature and stored concentration. This may be a significant issue during storage but is normally not significant in the context of dosing detention time. It can be reduced using dilution water which must be weighed against the negative impact of dilution water to control loop response (refer to section 3.1).

The degradation rate of sodium hypochlorite is significantly increased if the chemical is brought into contact with materials containing certain metals. Nickel is the most notable and common metal that accelerates decomposition of sodium hypochlorite. As nickel is present in many stainless steels and alloy steels, including those that are considered corrosion resistant to the chemical, use of these materials in contact with sodium hypochlorite must be avoided. Hastelloy C is sometimes selected for components in sodium hypochlorite service as it provides good corrosion resistance, however its high nickel content will significantly accelerate the degradation rate of the chemical. Special attention must be given to selection of pressure sustaining valves, check valves, dosing pumps and flow meter electrodes in this regard. Titanium and zirconium are the only metals that are resistant to corrosion in sodium hypochlorite service and do not cause accelerated degradation. The use of Hastelloy C276 for chemical dosing spears for sodium hypochlorite service is generally acceptable as the chemical has negligible time to degrade after encountering the metal.

2.2.8 Decomposition

Fluorosilicic acid will decompose on boiling/burning to form the extremely corrosive and toxic hydrogen fluoride gas. Double containment for this concentrated acid may not eliminate this hazard. In fact, a hard-piped above ground double containment system may increase this potential hazard in areas at risk from bush fires.

Dilution may reduce the requirement for double containment or enable use of a flexible pipe which can then be laid below ground and avoid this risk.

2.2.9 Reactions with dilution water impacting dosing efficiency

Coagulant and polymer dosing may be less efficient if a long time is provided for reaction with dilution water. Therefore, consider mixing neat chemical and dilution water in the field just before the dose point. Typically, this would involve running the neat chemical and dilution water lines in parallel from the dosing system out to the dose point in the field. Refer to section 3.3.5 and 3.3.6 for design considerations.

Dosing of other chemicals may also be less efficient due to reactions with hardness in the dilution water. Consider alternatives such as using softened water for batching then dose the batched chemical without further dilution. For example, use of hard dilution water with sodium fluoride solution[4] can result in "loss" of a significant percentage of the dosed chemical due to precipitation as calcium fluoride in the dosing line (downstream of the point of dilution). It is for this reason that dilution water is not normally used for sodium fluoride dosing.

2.3 Corrosiveness and Materials Degradation

Highly corrosive chemicals include all concentrated mineral acids (e.g. sulphuric acid, hydrochloric, fluorosilicic acids) and others such as ferric chloride. Oxidising and alkaline chemicals are also corrosive to inappropriately selected materials.

The corrosiveness and materials compatability can vary with chemical strength. General guidelines on suitable materials are contained in DS 33. Chemical strength varies from storage through dilution then dosing, so different material properties may be required for each of these situations if the corrosiveness changes. An interesting example is sulphuric acid which increases in corrosiveness when diluted below 98% w/w stored concentration. Concentrated sulphuric acid is hygroscopic and thus will absorb moisture from the air until it has reached equilibrium with the ambient relative humidity. Any such moisture entering the tank can lead to condensation and dilution of the acid. When the acid concentration decreases below 93% w/w then sulphuric acid can become corrosive to steel. With the diluted acid having lower density than the 98% w/w delivered product and being highly corrosive, accelerated corrosion of the upper portion of the mild steel tank can occur. This has implication for mild steel storage tanks where it is critical to remove moisture (humidity) from the air entering the tank when it empties and thermally "breathes". Strategies to control moisture ingress include desiccant dryers on the tank vent line and a silicon oil filled seal pot (U bend or similar vapour trap) on the overflow pipework.

2.4 Human and Environmental Risk Considerations

When considering the human and environmental risks associated with chemical dosing systems, reference should also be made to Section 4.4 of DS79 Design of Chemical Systems – Legislative Requirements and General Principles.

2.4.1 Human Health Risk

Most chemicals can have long term (chronic) or short term (acute e.g. asphyxiation, burns, headache, dizziness, nausea, vomiting, poisoning and, skin rashes) human health risks (in particular for O&M personnel) via any number of exposure pathways including:

- dermal;
- respiratory; and
- ingestion.

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[4] Note that to avoid this scale problem during batching of sodium fluoride, softened water is used to top up saturators to reduce the formation of insoluble products such as calcium fluoride building up and contaminating the sodium fluoride bed.

Dilution of chemicals such as most strong acids will likely reduce the severity of acute impacts with exceptions such as sulphuric acid which increases reactivity when diluted from 98 % w/w.

Further mitigation of risks shall be considered such as:

- elimination through design and current industry best practice;
- minimising manual processes and work tasks through automating processes;
- work procedures that minimise splashes and spills; and
- using protective equipment that is designed, constructed, and operated to ensure that the worker does not come into contact with the chemical.

2.4.2 Environmental Risks

Most chemicals present a potential risk to the environment if they escape from their containment systems. As well as direct ecological risk, there are reputational risks to the Water Corporation and the risk of fines if a chemical spill occurs. Where these risks are identified, the risk and its proposed treatment should be documented in the project's Safety in Design register and a Dangerous Goods manifest is required on site for emergency response.

In some cases, chemicals which pose low human health risk, can be highly toxic to flora/ fauna. For example, cationic polymers at low concentrations (and anionic polymers (acrylamide) at high concentrations) have potential to cause fish kills as the polymers attach and interfere with the oxygen receptor in their gills.

Dilution of chemicals such as strong acids may reduce the impact of any leak to the environment.

2.4.3 Lifecycle Impacts

Cost of disposal of treatment residuals must be considered when selecting chemicals. For example, selection of an aluminium-based coagulant may limit sludge disposal to class III/IV landfill sites with high fees and if remote from the treatment plant then also high waste cartage costs. There may also be other financial consequences from increasing the sulphate concentration in potable water leading to increased amount of hydrogen sulphide corrosion of assets in the wastewater system.

Circular economy opportunities which potentially reduce environmental impact and/or lifecycle cost impact should also be a factor in chemical selection.

2.4.4 Ergonomic Design

Where practical, location of dose points at waist height on a raised section of pipework is preferred because it provides optimum ergonomic access for maintenance and eliminates requirement for working in a confined space. Raised pipework may also be cost-effective if it avoids the need for a pit. However, this should be considered together with constraints such as:

- hydraulics;
- creating a barrier that impedes access to other areas of the plant;
- freezing of the dosed chemical more likely when above ground (e.g. neat caustic soda as discussed in section 2.1.4);
- degradation of the dosed chemical (refer to section 2.2.7); and
- decomposition of the dosed chemical (refer to section 2.2.8).

2.4.5 Barrier Protection

DS79-03 describes the risk assessment approach used to determine the appropriate barrier protection for each component of a chemical dosing system. For pipework running underground, double containment may not be necessary if the ground cover is sufficient and the chemical poses minimal risk to the environment. Use of pipe trenches (with lids/covers) is an effective method of barrier protection that also provides convenient access to pipework in circumstances such as maintenance, repairs and upgrades.

3 SYSTEM DESIGN

3.1 Start-up and Shutdown

Design of chemical feed and dosing systems needs to consider the outcomes of start-up and shut-down conditions, particularly relating to:

- whether there is a need for flushing of dosing lines on shut-down – for example, polyelectrolytes may degrade if left in pipe runs for long periods (refer to section 2.2.7.1);
- time taken for chemical solution to reach dose point on start-up;
- slurries that deposit on cessation of flow and require additional power input to “start” moving on resumption of flow;
- process control and monitoring to achieve required outcomes e.g. minimal dead times for disinfection chemicals to maintain effective, fail-safe residuals (for monochloramine reaction times refer to section 4.2.1.4);
- risks of not achieving required dose rate and mixing effectiveness during start-up and shut-down events – including during significant changes in flow rate. Risk mitigation strategies include:
    - **avoid dose line draining** by use of an automatic isolation valve or pressure sustaining valve in the field near the dose point. The advantage of an automatic isolation valve is it provides positive isolation which may be preferred if the consequence of the dose line draining is high, but it has the disadvantage of increasing complexity and control requirements.
    - **minimise volume of dose line.** Minimise length by locating dosing facility close to dose point (or bringing recipient main closer to the dosing facility). Minimise diameter by considering smaller pipes e.g. small diameter flexible PVC hose.
    - **use a “day tank”** with pre-diluted chemical with a Pressure Sustaining Valve just prior to dose point; hence, any change in dose pump speed will be rapidly transmitted to the dose point (i.e. minimal dead time since pressure transmits rapidly in a relatively incompressible fluid).

3.2 Dilution Risk Considerations

A significant benefit of dilution water is the enhancement of mixing in the receiving water. However, it is necessary to consider whether the benefit of using dilution water for a chemical dosing system outweighs any associated process disadvantages or risks.

If dilution water is intrinsic to the design – such as where water is required to dose gases in solution (e.g. chlorine gas, carbon dioxide) or for slurries - then advantage can be leveraged for mixing if required. If water is not intrinsic to the design, then the advantages and disadvantages when dilution/ carrier water is used must be carefully considered.

Table 3-1 summarises key risk areas for some more commonly used chemicals whether they be neat or diluted or at the point where they are injected into the receiving water.

The decision whether to dilute or not, and where to dilute, involves consideration of the chemical properties. For each chemical, the designer needs to consider the issues, risks and benefits of the feed chemicals - neat or with dilution / mixing water - in a fashion similar to that outlined in Table 3-2.

Table 3-1 – Common Chemicals and Risks

Common name	**Chemical Formula**	**Typical Supply Form/Strength**	**Key Issues - Undiluted**						**Key Dilution Issues**					**Injection Risks**		
			Degradation	Deposition/ scaling	**Change of phase**	**Corrosion**	**Human Toxicity**	**Environmental**	**Heat Rise**	**Scaling**	**Corrosion**	**Degradation / loss of effectiveness**	**Deposition**	**Heat Rise**	**Corrosion**	**Scaling**
DELIVERED LIQUIDS																
Alum (aluminium sulphate)	$Al_2(SO_4)_3.18H_2O$	47-50%w/w	🟢	🟢	🟢	△	△	♦	△	△	△	△	🟢	🟢	△	△
Ferric Chloride	$FeCl_3$	42% w/w	🟢	🟢	🟢	♦	♦	♦	△	△	♦	△	🟢	🟢	△	△
Sulphuric acid	H_2SO_4	98% w/w	🟢	🟢	🟢	△	♦	♦	♦	🟢	♦	🟢	🟢	♦	♦	🟢
	H_2SO_4	30% w/w	🟢	🟢	🟢	♦	△	♦	△	🟢	♦	🟢	🟢	🟢	♦	🟢
Fluorosilicic acid	H_2SiF_6	20-22%w/w	🟢	🟢	🟢	♦	♦	♦	△	△	♦	🟢	🟢	🟢	♦	🟢
Caustic Soda	NaOH	50% w/w	🟢	🟢	♦	♦	♦	♦	△	♦	🟢	🟢	🟢	🟢	🟢	♦
	NaOH	25-32% w/w	🟢	🟢	🟢	🟢	△	♦	△	♦	🟢	🟢	🟢	🟢	🟢	♦
Sodium Hypochlorite	NaOCl	10-12% w/v as Cl_2	△	🟢	🟢	△	△	♦	🟢	△	△	🟢	🟢	🟢	△	△
Sodium Bisulphite	$NaHSO_3$	33-35% w/w	△	🟢	△	△	△	♦	△	🟢	△	🟢	🟢	🟢	△	🟢
Citric Acid	$C_6H_8O_7$	50% w/w	🟢	🟢	🟢	🟢	🟢	△	🟢	🟢	🟢	🟢	🟢	🟢	△	🟢
Hydrochloric Acid	HCl	30-33% w/w	🟢	🟢	🟢	♦	♦	♦	△	🟢	♦	🟢	🟢	🟢	♦	△
Aqua ammonia	NH_3	25%w/w	🟢	🟢	△	🟢	△	♦	△	♦	🟢	🟢	🟢	🟢	🟢	△
Polydadmac Liquid Polymers	-	10-40% active	🟢	🟢	🟢	🟢	△	♦	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
DRY POWDER SOLUTIONS OR SLURRIES		**TYPICAL STRENGTH**														
Polyacrilamide powder	-	0.3% w/w	♦	🟢	🟢	🟢	🟢	△	🟢	🟢	🟢	△	🟢	🟢	🟢	🟢
Lime water solution	$Ca(OH)_2$	1400 mg/L	🟢	🟢	🟢	🟢	△	△						🟢	🟢	△
Lime slurry	$Ca(OH)_2$	2-8% w/v	🟢	♦	🟢	🟢	△	△	🟢	♦	🟢	🟢	△	🟢	🟢	△
GAS IN SOLUTIONS		**TYPICAL CONCENTRAT**														
Chlorine gas in solution	Cl_2	1,000-2,500 mg/L	🟢	🟢	🟢	△	△	♦	🟢	🟢	△	🟢	🟢	🟢	△	🟢
Ammonia gas in solution	NH_3		🟢	△	🟢	🟢	△	♦	🟢	♦	🟢	🟢	🟢	🟢	🟢	△
Carbon dioxide gas in solution	CO_2	2,000-5,000mg/L	🟢	🟢	🟢	△	🟢	🟢	🟢	🟢	△	🟢	🟢	🟢	△	🟢

🟢	No or low risk / probability
△	Medium or more likely risk / probability
♦	Definite or high risk / probability

Table 3-2 – Dilution Water Risks & Benefits

Issues to be considered for dilution water addition	Risk or Benefit	Context
Mixing in Receiving Water	Benefit	
Heat rise/ change of phase*	Risk	Concentrated mineral acids and alkalis especially sulphuric acid. Impact on piping cost to withstand high temperature, and pressure de-rating.
Boiling/vaporisation	Risk	Apart from boiling due to exothermic reactions, dilution may increase boiling point (e.g. ammonium hydroxide).
Scaling	Risk	Alkaline chemicals with calcium (or magnesium) in carrier water. Calcium chemicals with carbonate/ bicarbonates in carrier water.
Deposition Risk	Risk	Slurries - velocity to be kept high to maintain suspension.
Fouling Risk	Risk	All coagulants
Scaling/O&M	Risk Mitigation	May require duplicate lines, duplicate injection points, implementation of cleaning strategies (pigging, acid line alternation)
Viscosity reduction	Benefit	Polymers, anti-scalants
Flushing synergy	Benefit	Slurries, polymers; these typically need flushing; provision of carrier water may enable line flushing to be more readily carried out as part of system shutdown.
Freezing	Benefit	Some concentrated chemicals e.g. caustic soda
Loop response	Risk	All
Environmental	Benefit	Minor leaks will have a reduced impact on the environment due to reduced strength; however, more containment volume may be required.
OSH	Benefit	Dilution normally reduces the strength & toxicity of chemicals. In the event of a leak/ damage during maintenance, there is reduced risk, and may enable a reduction of PPE required or reduce requirement for double-containment.
Cost / O&M	Risk	May require duplicate pipes to manage scaling risks. May require more instruments/ control
Cost	Benefit	May avoid need for double containment. May enable a single (diluted chemical pipe) rather than separate duplicate pipe chemical and water pipe to injection point.
System shutdown	Risk	In particular for concentrated H_2SO_4. There will remain a small acid – water interface which will continue to generate heat/generate boiling risk. Consider dilution water run-on for a brief period once acid dose pump stops. Polymers etc. - potential loss of effectiveness for longer shutdowns. Deposition/ cementing of slurries. Need for flushing.
Decomposition	Benefit	Reduced risk of H_2SiF_6 decomposition in extreme heat e.g. bushfires.
Degradation	Risk	Polymer loss of efficiency if carrier water has high chlorine content.

3.3 Chemical Reactions

The control of the process, in particular feedback for automated process loop control needs to account for the time for chemical reactions to complete. Process control is discussed in more detail in Section 4.2.2.

It is a general requirement that sufficient contact time is provided for any chemicals dosed.

3.3.1 pH and Alkalinity Management

Measure	Rationale	Additional Information
Sufficient dilution, mixing and contact time is provided for any chemicals dosed.	Any chemical reaction (oxidation or coagulation) requires uniform pH for complete reaction with uniform formation of particulates and floc.	Typical chemicals used include lime, soda ash, caustic soda and carbon dioxide. The chemicals should be well mixed with the water prior to any unit process. Typically, a dilution ratio of 20:1 is preferred.

3.3.2 Oxidation

Measure	Rationale	Additional Information
Sufficient contact time is provided for oxidation.	For complete or near complete conversion of soluble metals or other compounds sufficient contact time is required.	The time required for oxidation is typically determined by pilot, jar testing or knowledge of process, and will also depend on the oxidant and contaminants in the raw water. It will also depend on treatment type (e.g. membrane, media filter).
Dosing of oxidant is well controlled to the setpoint (e.g. ORP).	Under or over-dosing of oxidant can lead to the contaminant, or in some cases the oxidant itself, passing through the treatment process and the production of poor water quality.	Where there are multiple sources/varying raw water quality, the oxidant dosing shall be flow paced and use a suitable feedback trim (e.g. ORP). Frequent variations in source water quality require a faster acting control loop with analyser sample from the filter inlet in preference to the outlet. Take care to select an analyser that can handle the solids loading in the sample.
Required pH[5] for oxidation is maintained.	Oxidation can be highly sensitive to pH and should be optimised for the treatment objectives.	pH monitoring for oxidation is mandatory for pathogen plants, and optional for aesthetic plants.

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[5] The rate of oxidation is also temperature dependent.

3.3.3 Disinfection

Measure	Rationale	Additional Information
Ensure adequate Ct (Concentration x time)	Provide sufficient dose and contact time to achieve the required extent of pathogen inactivation.	Disinfection targets for groundwater are in the Criteria for Drinking Water Supply and for surface water are in the Surface Water Treatment Manual.
Consider where short circuiting may occur post disinfection chlorination as it compromises achievement of Ct.	Short circuiting may cause inadequate disinfection and may result in increased residual decay that in turn may cause the barrier to re-contamination to be inadequate.	The Surface Water Treatment Manual explains application of baffle factor for chlorination to determine a realistic estimate of Ct.

3.3.4 Powdered Activated Carbon (PAC) Adsorption

Measure	Rationale	Additional Information
Sufficient contact time and mixing is provided for adsorption of contaminants by the PAC.	For satisfactory adsorption of organic contaminants sufficient contact time is required.	A contact tank with sufficient mixing to suspend the PAC is preferred. Dosing into raw water pipelines is another option but note that PAC is abrasive and may damage any fittings or instruments in the pipeline. At design flow, at least 15 minutes and preferably 30 to 60 minutes of effective contact time is required depending on the organic contaminant to be removed. It is important to note the variable performance of some PACs; this should be investigated as part of the selection process and to determine adequate contact time.

3.3.5 Coagulation

Coagulation (by addition of a coagulant) destablises the electrostatic charge on a substance, which overcomes the tendency of the charged particles to repel each other and allows them to group together.

Measure	Rationale	Additional Information
A well-designed mixing system (static or mechanical) is provided for coagulant mixing.	Optimised coagulation is dependent on rapid and thorough mixing of the	Well-designed mixing systems vary between flash or rapid mixers (inline or in tank) of various designs to static mixers

Measure	Rationale	Additional Information
	coagulant and the raw water to promote particle collision.	or long sections of pipe with sufficient bends and fittings.
Appropriately sized, graduated calibration tubes, calibrated flow meters or mass flow meters are provided to measure the amount of coagulant or flocculant dosed.	Accurate dosing of coagulant is essential to maintain optimal coagulation.	Calibration tube size should be such that in one minute the liquid drops a distance at least equal to the diameter of the tube.
There is a system to detect the loss of coagulant dosing, including carrier water.	Compromised or failed coagulation results in reduced pathogen removal. In systems where carrier water is added at the dosing skid, a loss of carrier water can result in under dosing.	Methods[6] of detection include: • flow meters (coagulant) and flow switches (carrier water). • online UV254 and insitu DOC/TOC or UV-Vis spec (S::CAN) • streaming current detectors or zeta potential meters (however, they both are only beneficial in surface water) • pH meters • level sensors in storage tanks • inference from variation in pump speed required to deliver dose.
Chemical dosing is flow paced.	The dose of coagulant is critical to the success of the coagulation process and must be accurately and proportionally maintained at all flow rates.	Volumetric draw down check should be undertaken regularly and at different flow rates to confirm accuracy. This requirement needs to be included in the O&M manual.
Chemical dose rate is optimised.	Jar testing should be performed regularly or upon significant changes in raw water quality.	Additionally, can also be controlled using online UV-Vis spectrometry (e.g. S::CAN).
Dilution of coagulant with carrier water is at least 20:1.	Dilution assists even dispersion and mixing which is essential for optimal coagulation. Over-dilution can compromise coagulation.	Over-dilution can compromise coagulation. Minimise contact time (ideally 2-3 seconds, refer to section 4.3.5.1) with dilution water before dosing.
The order of chemical addition has been optimised for	The order of chemical addition is important to achieve all	Many treatment processes are compromised by incorrect

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[6] A combination of these methods may be warranted. Common requirements are that a flow meter will confirm the intended dose was applied, and a flow switch will confirm flow of carrier water. Preferred methods of monitoring coagulant dosing effectiveness are online UV254 and *in situ* DOC/TOC or UV-Vis spectroscopy (S::CAN). An in-line instrument such as streaming current detector (suitable only in surface water treatment) may be used to ensure the dosing conditions are optimum (which also confirms that the coagulant reached the dose point). Streaming current detectors are efficient where the raw water chemistry alters due to season etcetera and the coagulant dosing must vary to ensure charge neutralisation, thus effective coagulation. Level sensors in a storage tank is a very minimalist approach (confirming chemical available for dosing) and would normally be used in conjunction with other monitoring.

Measure	Rationale	Additional Information
coagulation, with sufficient time between each addition to allow for the completion of the chemical reaction process	treatment goals. In most cases, the order is: pH correction, oxidation, coagulant, coagulant aid.	sequencing of chemicals and/or insufficient time for the reactions to take place.

3.3.6 Flocculation

Flocculation is the growth of small, neutral particles into larger particles. It typically involves:

- addition of a flocculant to promote clumping of fine particles into 'floc'; and
- gentle mixing to increase size of the particles from micro-floc to large, visible suspended particles that can then be readily separated from the water.

Measure	Rationale	Additional Information
Turbulence after the formation of floc is minimised.	Post flocculation turbulence can cause floc shearing. Floc generally reforms poorly once it is disrupted and may result in higher filtered water turbidity and higher pathogen risk to consumers.	Determine flocculation times by jar test. Typical flocculation times are between 5 – 45 minutes.
Flocculation time is between 5 and 45 minutes depending on water temperature.	Water temperature has a significant effect on flocculation.	The critical transition temperature between slow and faster flocculation is typically around 10-12°C. In some instances, the flocculation tank should be heated to maintain a steady solution temperature to ensure consistent mixing.
Flocculators run continuously (24/7), even during plant shutdown.	Intermittent operation allows settling of floc and compaction which increases the risk of carryover of material to the filters on start-up. Continuous flocculation allows the treatment plant to return to optimum operation after start-up more quickly.	Options available to re-suspend floc (turn down flocculator speed, filter to waste on startup, turn flocculator on before the rest of the WTP) depending on plant set up.

For polymer, use a static mixer in the solution line to achieve thorough mixing prior to the dose point; the viscous nature of polymer inhibits mixing from pipe turbulence (due to the pipe walls and fittings), causing inefficient polymer dosing unless a static mixer is used. Water Corporation experience is that 0.02% w/w is the optimum concentration for the diluted polymer.

3.4 Process Controls

Chemical dosing shall be flow-paced for any application that has a varying flow rate.

To trim the chemical dose rate, a feedback control option shall be provided for any process in which the design includes an online analyser that provides a process variable which correlates closely with the chemical dose rate. Alternatively, some plants use online UV/Vis monitoring to achieve feed forward trim control (e.g. Mirrabooka, Wanneroo, Jandakot and Harding Dam WTPs).

3.4.1 Minimising control loop time

Control loop time is the accumulation of multiple aspects:

- dosing system design - Time for a change of dose rate to be propagated to the dose point;
- mixing design - Time/distance for (a) the dosed chemical to be fully mixed (refer to section 4), and (b) chemical reactions to occur (refer to 3.3);
- Analyser configuration - Time for the sample to reach the analyser (refer to 3.5.6.1); and
- Analyser selection - Time for the instrument to analyse the water sample.

Controllability of chemical dosing benefits from minimising control loop time. It cannot be over-stated how important control loop time is to the performance of a dosing system that employs feedback control.

Generally[7], excellent to very good controllability is achieved with a loop time less than 3 minutes, which should be the target of the process design. Acceptable controllability is achieved with a loop time of less than 5 minutes however this should only be accepted where it is not practical to achieve less than 3 minutes.

Options for minimising control loop time include:

- Minimising time for dose rate changes to be propagated to the dose point:
    - For liquid dosing systems, consider designing without the use of dilution water in the chemical dose line (when no dilution water is used, changes in dose pump output propagate instantaneously to the chemical injection point). An alternative compromise where dilution water is desirable to improve initial mixing at the dose point is to add the dilution water as close to the dose point as practically possible.
    - Use another dosing pump for dilution water that is higher capacity (selected based on desired dilution ratio) than the chemical dosing pump. By operating the chemical dosing pump and the dilution water dosing pump in proportion (even using the same 4-20mA signal to run both dosing pumps) then the dosing line becomes constant concentration / variable flow and therefore has zero control dead time. This retains the safety benefits of dilution, allows rapid filling of the dose line after maintenance, but without the negative impact to process control. Of course, it adds the cost, complexity etc. of another dosing pump.
    - For gas and liquid dosing systems where dilution water is added to the chemical dose line, locate the chemical dosing system as close as possible to the dose point.
    - Re-route or divert the water line (i.e. move dose point) to bring it closer to the chemical dosing system.
    - For gas and liquid dosing systems where dilution water is added, maximise the velocity of the dose line. i.e. smaller dosing lines and/or use of dilution water to achieve high velocity.
    - For gas dosing systems, locate vacuum ejectors close to the dose point(s) (gas vacuum lines generally exhibit lower dead time than solution lines).
    - Minimise hysteresis (refer to 3.5.3).
- Minimising time for the chemical to be mixed into the recipient water main

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[7] Note that 3-5 minutes is not suitable for chloramination – up to 15 minutes may be required.

  - Use of dilution water provides high velocity injection into the recipient main.
  - Use of a multi-port dosing spear to shorten mixing length allowing the sample point to be located closer to the dose point.
  - Use of a static mixer to shorten mixing length allowing the sample point to be located closer to the dose point.
- Minimising time for the sample to reach the analyser
  - Use an in-line analyser either directly in the recipient water main or in a short length of parallel line with appropriate isolations for sensor maintenance (e.g. pH probe, conductivity probe, chlorine probe).
  - Locate sensors / analysers in the field near the dose point (i.e. travel time short if within a few metres).
  - Provide a high-rate sample pump (which typically circulates sample water to the analyser panel at high velocity then back into the water main). Sample water to one or multiple analysers is then taken from this line.
- Minimising the time for the analyser to read the sample (and provide a stable reading at the new concentration)
  - Continuous analysers (e.g. amperometric and polarimetry probes) generally detect (and stabilise reading) changes in the analysed parameter more rapidly than batch style (reagent) analysers.
  - Use a dedicated analyser for critical sample points (e.g. for feedback control) and limit multi-stream analysers to non-critical (e.g. monitoring only) sample points or for batch processes (e.g. CIP of multiple membrane trains).
  - Configure multi-stream analysers to normally service the critical sample point (feedback control) and at long intervals take a brief “peek” at non-critical (monitoring only) sample points. An example of this is implemented in the Water Corporation’s standard chlorination designs (DS70 and DS73).

3.4.2 Control Loop Interactions

Occasionally designers will encounter combinations of dosing systems that interact strongly with each other or are strongly coupled with other non-dosing control loops. Examples include:

- RO permeate potabilisation systems using lime and CO_2 where the design objective is to achieve both an alkalinity and pH target, yet one chemical is acidic, and one is basic; and
- lime water preparation and dosing systems where multiple control loops for pH control, tank level control, milk of lime addition (to lime water clarifier) and water makeup controllers (to lime water clarifier) all interact significantly.

3.4.3 Control logic

Control logic shall be developed in accordance with the Control Logic section of DS81.

3.5 Piping and Equipment Configuration

Design must start with first principles considerations such as chemical and physical properties, as well as potential chemical and physical reactions.

3.5.1 Drafting requirements

Show all pipework (dose, sample and air lines) on drawings (e.g. on General Arrangement and Section drawings of the Process Area). This is important for considerations such as operability and maintainability.

P&IDs shall correctly show boundaries for dose panels as well as any compartment separations within a dose panel. General requirements for drafting P&IDs are defined in process engineering design standard DS81.

3.5.2 Piping

3.5.2.1 Material selection

General guidance on material selection is contained in general mechanical design criteria standard DS30-02. Information on material selection for specific chemicals can be found in the below design standards:

Chemical	Design standard
Chlorine Gas & Chlorine Solution	DS70-20/30
Fluorosilicic Acid	DS71-01
Lime, Milk of Lime & Lime Water	DS72-01
Sodium Hypochlorite	DS73 set
Sodium Fluoride	DS74

Specific requirements for PVC pipe in chemical service, including primer and solvent cement selection and application requirements are contained in pipework mechanical design standard DS31-01.

For small dosing systems and for connections to dose pumps, consider use of flexible PVC hose instead of larger pipe because it:

- avoids issues of chemical compatibility with the solvent cement;
- minimises dose line volume (assists minimising hysteresis- refer to 3.5.3.2);
- has low installation cost; and
- is easy to install in a double-containment system.

Where used, flexible hose material shall be compatible with the chemical. The preferred hose type is braided clear PVC minimum PN16 hose (e.g. 6 mm ID/12 mm OD by Rehau Rauiflam-E). However, where hoses are used outdoors or use compression fittings in hot environments, alternative materials such as ETFE which have a lower rate of temperature pressure de-rating and softening with temperature shall be employed. Hoses shall be protected from direct sunlight.

Scale is less likely to bond to polyethylene than PVC pipework; hence, use of polyethylene dose lines and polyethylene lining/coating of dosing spears is a potential method to minimise rate of scale accumulation.

3.5.2.2 Chamfers

Use chamfers/bevels when solvent cementing pipework. Chamfers (typically, a few millimetres in length at an angle between 10 and 15 degrees) remove the “sharp” edge that may otherwise wipe/push the glue off the inside of the joint. If glue is pushed off the inside of the joint, then a poor-quality joint may result, which may result in leakage. Prior to priming and solvent cementing:

- remove the jagged edge (burr) on cut pipes; and
- the leading edge of cut pipes shall be chamfered in accordance with installation instructions from the pipe manufacturer.

Chamfers can be made using a hand bevelling tool specifically designed for use with plastic pipe, metal file (rather than a wood file which is rougher), wood scraper, grinder on larger pipes (use a zirconium flexible grinding disc rather than sanding disc), or chamfer tool (as a drill fitting).

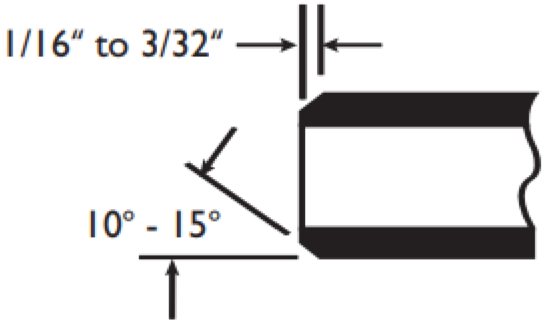

Figure 3-1 – Chamfer on a PVC pipe (source: GF Harvel Installation Guide)

3.5.2.3 Primers

Primers clean and etch the pipe surface where it is to be joined, thereby providing a better joint when solvent cemented. Evidence is required that a joint was primed prior to painting. If the primer recommended by the pipe system supplier is only available as clear primer (e.g. Tangit Cleaner), then the required evidence is dulling and clean wipe marks; otherwise, a stained primer is preferred. This allows validation that each joint has been primed. The validation shall be by inspection prior to painting.

3.5.2.4 Solvent cements

For chemical dosing and sampling pipework, PVC-U pressure pipework used shall be Schedule 80, manufactured in accordance with ASTM D1785. Use only the gap filling cement recommended by the Schedule 80 pipe system supplier because this contains no additional fillers since it is only PVC-U dissolved in solvent i.e. once the solvent evaporates from the joint, only PVC-U remains. By contrast, some other PVC solvents contain silica that is attacked by chemicals such as sodium hypochlorite which dissolve the silica over time leading to pipe joint failure.

For the chemicals listed in Table 3-3 below, only Tangit Cleaner and Tangit DTX shall be used for solvent cement jointing.

Table 3-3 - Only Tangit Cleaner and Tangit DTX Solvent Cement to be used for these Services

CHEMICAL SERVICE	CONCENTRATION OF CHEMICAL (% w/w)
Sulphuric Acid	$\geq 70\%$ H_2SO_4
Hydrochloric Acid	$\geq 25\%$ HCl
Nitric Acid	$\geq 20\%$ HNO_3
Sodium Hypochlorite / Calcium Hypochlorite	$\geq 6\%$ NaOCl active chlorine
Hydrogen Peroxide	$\geq 5\%$ H_2O_2
Hydrofluoric Acid	Any HF concentration

For PVC pipe in any of the above chemical service, include a note on P&IDs to state only Tangit primer and Tangit DTX solvent cement shall be used.

3.5.2.5 Joints

Minimise joints in dose lines because these are potential failure points. Options to achieve this include use of PVC hose rather than a jointed pipe system, or if using a jointed pipe system then maximise straight uninterrupted sections (i.e. minimise use of connector fittings).

3.5.3 Hysteresis

In dosing systems, hysteresis is the delay of a change in the dose flow rate being propagated to the dose point.

3.5.3.1 Pulsation dampeners

The bladder in a pulsation dampener compresses with increased dosing system pressure, which results in volume expansion of the dosing system (delaying the change in flow rate of the chemical), and similarly with reduced dosing system pressure the pulsation dampener expands which acts to sustain the flow of chemical. This delays complete propagation of the altered dose pump output to the dose point.

Omitting pulsation dampeners is desirable from the perspective of minimising hysteresis. However, pulsation dampeners may be required to protect pipework from vibration-related fatigue induced by operation of the dose pump. This requirement depends on the style of dose pump selected and the way the pump is connected. Note that pulsation dampeners are not the only way to provide steady dosing because this can now readily be achieved through use of digital dose pumps that have a controlled steady discharge stroke followed by a rapid suction stroke, which results in near-continuous delivery of chemical at the required dose rate. Additionally, transfer of vibration can be further minimised using flexible pipework to connect the dosing pump to rigid pipework. Approval to not install a Pulsation Dampener shall be obtained from the Senior Principal Engineer Water Treatment or Senior Principal Engineer Mechanical.

3.5.3.2 Dose lines

Flexibility of the dose line material results in a change of dose line volume in response to changes in pressure delivered by the dose pump. Considerations for minimising this problem include:

- avoid over-sized dose lines (diameter and length) as they provide additional volume which can exacerbate dose line swelling with pressure; and
- material selection to consider flexibility of the dose line material.

3.5.3.3 Pressure Sustaining Valves

The pressure sustaining valve serves three purposes:

- the back pressure ensures rapid and effective seating of check valves in the dosing pump head. Dosing pump manufacturers specify minimum differential pressure requirements across the dosing pump for this reason;
- it prevents siphoning of chemical through to the dose point (hence it minimises hysteresis); and
- for long dose lines, a second pressure sustaining valve located in the dose line just before the dose point and set to a minimum pressure can prevent draining and diffusion of chemical into the water line when the chemical dosing system is not running (no flow). Note that setting this second pressure sustaining valve to a high pressure can result in surging in the dose line due to the combined effect of hysteresis in the valve and resulting expansion and contraction of the dose line.

For the pressure sustaining valve near the dosing pump discharge, specify the pressure setpoint just above the system operating pressure (and preferably also above transfer pump start-up pressure to avoid a brief interruption of dosing because the pressure sustaining valve will not open). The pressure sustaining valve needs to be selected for the appropriate dosing flow rate and with low hysteresis. Over-sized valves or valves with high hysteresis can cause discontinuous dosing due to surging in the dose line.

3.5.4 Equipment

3.5.4.1 Calibration tubes

Calibration tubes are used to calibrate dose pumps. This is normally undertaken at commissioning or after maintenance/replacement of the dose pump. In some systems, the infrequent use of calibration tubes may (subject to Regional preference) allow a calibration tube to be shared (i.e. relocated) between duty and standby dose pumps.

Calibration tube size should be such that in one minute the liquid drops a distance at least equal to the diameter of the tube. Thus, the cylinder capacity will be equivalent to the volume pumped at maximum dose for about 5 minutes.

The design shall allow the calibration tube to be gravity filled from the chemical storage tank so that the pump can be safely calibrated on the chemical being dosed without manual handling of chemical.

For some chemicals it might not be (subject to Regional preference) necessary to have a calibration tube (e.g. if the chemical is dosed to achieve a pH value rather than a target concentration, especially for intermittent processes such as Clean-In-Place), whereas for a coagulant dose the objective may be to match the concentration determined in jar tests; hence, a calibration tube would be required.

3.5.4.2 Dose pumps

Guidance on selection of dose pumps is contained in the Chemical Dose Pumps section of DS32. In addition to the guidance in DS32, note that the Strategic Products Register lists digital dose pumps which provide performance benefits such as very high turndown ratio.

Consider use of flexible hoses to connect dosing pumps to rigid pipework, which:

- minimises transfer of vibration from the dose pump to the rigid pipework;
- provides easier installation/maintenance of the dose pump (compared to rigid pipe);
- allows future installation of replacement/upgraded dose pumps with different dimensions; and
- allows the dose pump to be mounted lower than the dosing panel (i.e. for positive suction pressure the dose pump may need to be at floor level).

3.5.4.3 Flow metering

Flow metering of the dosed chemical is required where it is critical to verify that a particular flow rate is achieved. Examples include:

- chemicals whose dose rates are based on jar tests (e.g. coagulant) and not trimmed using signal from a process analyser; and
- fluoridation i.e. FSA or sodium fluoride (to ensure maximum dose is not exceeded).

An example where chemical flow metering is typically not required is for chemical dosing that is pH trimmed.

Some metering pump manufacturers now sell “digital” dosing pumps that include optional Integrated Flow Metering (IFM) or Flow Computer Modules (e.g. Grundfos “FCM” option). Typically, these options do not use an actual flow meter but rather infer the flow rate of the dosing pump based on speed, pump head pressure cycles and other parameters that are monitored within the dosing pump. The resulting inferred flow can be very accurate. Digital dosing pumps with these IFM options are now commonly used in small capacity Water Corporation chemical dosing facilities.

Standalone flow meters (such as mini magflow meters) generally provide higher reliability and accuracy of measurement validity than Integrated Flow Metering (IFM). Therefore, standalone flow meters shall be installed for:

- risk management (system protection) when there is no other process feedback (i.e. analyser) to verify the dose and the dose is critical to the downstream process performance/life (e.g. anti-scalant for RO);
- risk management (system protection) where process safety requires that standalone flow measurement is required for critical asset protection and/or personnel safety. This requirement would typically be determined in the HAZOP and the Process Safety Plan;
- risk management (system protection) where there is a need to verify that there is or is not any flow. If this were the only requirement, then a possible alternative is to use a combination of a flow switch and IFM; however, since flow switches are generally less reliable than flow meters, then this alternative will require risk assessment and acceptance by the client Region/Operations;
- applications where IFM may not be suitable because of varying delivery pressure if the dosed solution has a propensity to foul or scale the dosing pipework;
- applications where accurate level/volume readings are not possible from the supply tank. Typically, the level of accuracy needs to be sufficient to verify that the tank either contains sufficient chemical to supply the pump or where accurate records of chemical usage are required;
- cost management (chemical cost) e.g. for chemicals with high unit cost such as anti-scalants; and
- regulatory reporting purposes e.g. DS71-01 states that magflow meters shall be used for FSA (and similar applies to sodium fluoride dosing).

IFM as a sole flow measurement strategy would typically be suitable where precise dose rates are not critical e.g. Clean-In-Place (CIP) systems, or dosing wastewater with coagulant for phosphorus removal. IFM may also be considered for sodium hypochlorite dosing of reuse water provided that there is reasonable evidence that the dose rates will be sufficiently accurate to be within the target range for chlorine residual concentration.

3.5.4.4 Flow switches

Flow switches are used where it is required to verify that a minimum flow rate has been achieved when no other flow measurement is provided. They shall be used to verify flow exists in dilution water systems.

3.5.4.5 Dosing spears

Receiving Water Velocity

Spears must be designed to cope with bending and vibration effects from the water flowing across the spear. If spear length exceeds the allowable unsupported length, they need to be supported or “potted” at the other side of the main pipe to reduce working stress. Consideration must still be given to the potential effect of velocity / forces if the spear is designed or needs to be withdrawn whilst the main is flowing. Note that the Water Corporation standard design of dosing spears (refer to section 3.5.4.5.4) for large water mains uses a pair of half-diameter spears in a perpendicular arrangement, rather than a full diameter spear “potted” at the other side of the main pipe.

Scaling Considerations

Where scaling is a potential issue within the spear and/or the receiving water pipe, the designer shall consider the need and benefit of:

- duplicate / standby spears;
- in-situ cleaning (refer to section 2.2.5);
- dosing backpressure and/or flow monitoring;
- larger orifices;
- HDPE coating of the spears (refer to section 3.5.4.5.1); and
- easy removal for external cleaning of the section of receiving water pipe that is expected to scale.

Intermittent Flow Considerations

In most systems, both the receiving and dosing flow will be intermittent. The installation will need to consider means to reduce or eliminate inter-fluid mixing in non- dosing periods both from the dosing line into the receiving water and from the receiving water into the doing line. This may include consideration of check valves and automatic flushing arrangements.

3.5.4.5.1 *Dosing Spear Materials*

Chemical compatibility shall be considered when selecting dosing spear material. The standard design for dosing spears uses SAF2205[8] because it provides reasonable life expectancy with most chemicals (but not sodium hypochlorite) and is less expensive than Super Duplex Stainless Steel.

Dosing spears for the dosing of sodium hypochlorite solution with concentration up to 3000mg/L (0.3% w/w) shall be manufactured from Super Duplex Stainless Steel with a Pitting Resistance Equivalent Number (PREN) of 40 or higher. Dosing spears for higher concentration sodium hypochlorite solution shall be manufactured from Hastelloy C276 or titanium.

Where there is a high likelihood of scale formation, consider use of HDPE-coated dosing spears as these have lower rates of scale accumulation/adhesion compared to uncoated steel spears (based on results from a trial at Perth Seawater Desalination Plant Nexus # 49719881). The HDPE coating should cover all exposed surfaces of the steel spear (refer to Figure 3-2 which shows HDPE coating folded over the orifices).

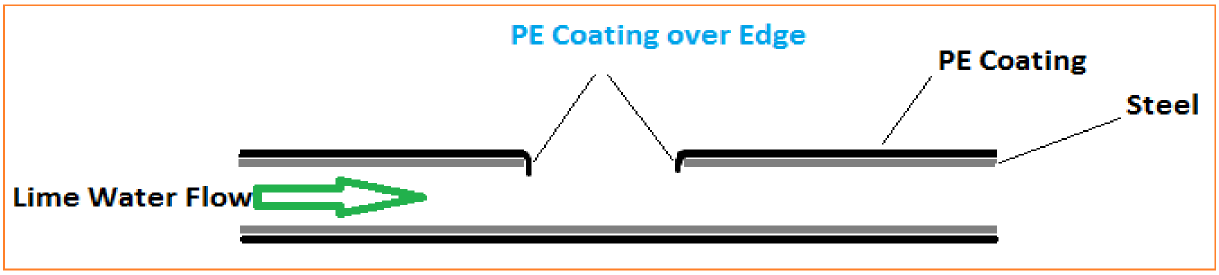

Figure 3-2: Illustration of dose spear with PE coating on outside and folded over orifices

3.5.4.5.2 *Retractable Dosing Spears*

Spears come in two general types which are either retractable or fixed. The Water Corporation standard design is for fixed dosing spears. Only one model of retractable spear is currently approved by the Water Corporation for extraction under pressure – refer to Table D of the Strategic Products Register.

Alternative retractable spears shall only be considered where the required force ("ejection force") to insert or retract the spear is less than 120 Newtons. Withdrawal of spears is considerably more complex than for quills. If the spear must be withdrawn under pressure before the main can be isolated, significant water will be back-fed via the spear orifices as it is withdrawn. To avoid this problem, a custom-designed retraction sleeve is typically required, which is at least as long as the spear, and external to the pipe.

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[8] Stainless Steel UNS S322025, EN 1.4462

Spears are usually of larger diameter than quills and therefore will be subject to proportionally more ejection force. The safety of withdrawing spears under pressure must be addressed by the designer.

Retractable dosing spears are used in moderate size and pressure applications and are designed to be safely removed from the live main for cleaning or de-scaling without the need for major shutdown.

CAUTION! The insertion or retraction of a dosing spear into a pressurised pipeline can represent a significant safety hazard. The 'Pressure x Area' force on the spear acts to accelerate the spear once the gland friction is released. In the event of an uncontrolled release of the sealing gland, the dosing spear has the potential to become a dangerous projectile.

To **mitigate this risk**, retractable dosing spears shall be:

- limited in diameter and pipeline pressure such that an operator insertion force of not more than 120 Newton is required to force the spear into the main; and
- limited in length to not more than 600 mm (note that length of insertion into the main is less than this due to length lost between the flange and the main).

Note that some old systems have chains whose purpose is to provide measurement for incremental retraction but are not effective at restraining the spear from becoming a projectile.

3.5.4.5.3 Fixed Dosing and Sampling Spears

A fixed (non-retractable) spear cannot be removed from a pressurised water main with flowing water. The main must be isolated, pressure relieved, and water drained to a level below the spear, before its removal from the water main. Drainage is generally easier to achieve in an above ground section of pipework. Specific design provision is required to drain the section of main containing the spear(s):

- to minimise the length (and volume) of pipe to be drained - provide isolation valves as close as practical upstream and downstream; and
- to allow water to drain – provide a scour outlet at the local low point and a vacuum (i.e. double-acting) air valve at the local high point, both of which are to be sized for rapid draining of the pipe section (i.e. not exceeding 30 minutes).

Fixed dosing spears in larger lengths have previously been prone to vortex induced vibration (VIV) with recorded failures in the Corporation's assets. For this reason, standard designs have been developed which are based on API thermowell standards, these designs ensure structural stability at pipeline flow velocities of up to 5m/s. These are detailed in the report Chemical Dosing Spears – Structural VIV and Mixing Performance Assessment (Nexus # 54152435). The spacing of orifices have been based on dividing the pipe up into equal area segments. Dosing Spear Sizes and details for various pipeline diameters are provided in the standard drawings referenced in section 3.5.4.5.4 below.

3.5.4.5.4 Standard Drawings for Fixed Dosing and Sampling Spears

The following standard drawings form the basis of fixed spear designs:

JZ39-002-001-01 Typical Dosing Array - General Arrangement

JZ39-002-002-01 Typical Sampling Array - General Arrangement

JZ39-002-003-01 Dosing Spear for Pipe Size DN800 and Larger

JZ39-002-004-01 Dosing Spear for Pipe Size DN700 and Smaller

3.5.4.6 Sample pumps

Stainless steel in-line centrifugal pumps are generally the preferred type of sample pump because they are reliable and low maintenance. In contrast, progressive cavity pumps may be susceptible to stator wear (replacement at 6-month intervals) which also causes sample contamination by disintegration debris from stator wear.

Microgear pumps have found some useful application in regulating the sample flow to a single on-line analyser where there is a wide range of operating pressure at the sample offtake point.

Pump design requirements shall be in accordance with DS32.

3.5.4.7 Sample pipework

Provide means to flush sample lines upstream of pressure regulators.

Provide sample points at locations suitable for verification of on-line analysers.

Pipework design/layout to minimise build-up of air or released dissolved gasses in sample cells.

Provide and/or connect to a sample water recovery/disposal system (refer to section 3.5.6.6).

3.5.4.8 Pits

The hierarchy of controls favours ***elimination*** of hazards associated with pits such as confined spaces, falls and engulfment risks i.e. pits must not create a confined space hazard, fall or engulfment risk. Therefore, where practical provide access to the pipework by bringing the pipework aboveground so that magflow meter, dose point and sample points are in a raised section of pipework.

In many instances, magflow meters do not require access until they need replacement; hence, it may be economic to bury magflow meters i.e. the lifetime cost of safely excavating the magflow meter at infrequent intervals may be significantly less than the cost of constructing a pit. Where Regional preference is not to bury magflow meters, then this may be a further factor favouring bringing pipework aboveground.

Where pits are required, access stairs may be necessary to mitigate the confined space hazard.

3.5.5 Access, Maintenance and Safety

The designer shall consider safety and maintenance of the dosing point, including:

- access to spears/quills and adequate withdrawal length;
- provision for flushing;
- orientation of the installation;
- flexible hoses and unions to allow disassembly and reinstatement of dosing spear pipework with minimal downtime during maintenance and/or component replacement;
- provision for Lock Out Tag Out (LOTO); and
- chemical barrier protection (refer to DS79-03) that allows maintenance to be performed safely on the standby system while the duty system is in operation.

3.5.6 Analysers

Analysers shall be selected, and their installation designed, in accordance with Field Instrumentation design standard DS40-09. Note that DS40-09 contains a section on General Design Principles and a section on Analytical Instruments which describes requirements for each type of analyser.

Analytical instruments are affected by both ambient temperature and process temperature. Many types of analysers will require an air-conditioned enclosure to ensure the instrument performs to the required accuracy and reliability. This includes the reliability of any LCD displays on instruments, which often become unreadable when installed in a hot environment (e.g. air-conditioning was required to be retro-fitted to many chlorination rooms where chlorine analysers are installed due to instrument LCD displays going black) or where they are exposed to direct sunlight. Whole-of-life cost analysis should be used to assess alternatives such as cabinet cooling rather than cooling an entire room, and consider whether there is opportunity to install the analyser within a room that already has air-conditioning provided.

3.5.6.1 Analyser sample configurations

Online instruments shall be positioned as close as possible to the point of sampling, and it is required that the time for the sample to reach the analyser is known. Sampling should be from the middle of the pipe in most cases (especially small diameter mains), though multi-port sample spears are preferred in medium/large diameter mains. Designers should also consider the manufacturer's installation specifications. Where analyser reagents are used, their use and disposal should also be considered (refer to section 3.5.6.6).

In-line analysers minimise loop time and are the least complicated (avoiding sample pumps, air-conditioning requirement, and pumped sample water recycling system) and therefore may have lower capital and operating costs. However, maintenance of inline analysers is more complex.

An alternative with moderate loop time is to use an off-line analyser in a field-mounted cabinet located as close as practical (i.e. minimise hydraulic retention time) to the sample point (typically within a few metres of the sample point). Although analysers remote from the sample point have longer loop time, they have the convenience of locating all equipment in one place (such as within a pre-fabricated treatment module).

Table 3-4 – Comparison of Analyser Configurations

Configuration	*Advantages*	*Disadvantages*
Direct process measurement		
In-line	Minimum loop time	Probe less convenient to remove for cleaning and calibration
	Fast moving sample minimises fouling of probe	Field measurement may be a less secure location requiring provision of additional protection.
	No sample water disposal	
Bypass process measurement		
Off-line on field panel	Low loop time	Slow sample velocities allow growth/clogging in sample lines
	Probe easy to remove for cleaning and calibration	Requires sample water disposal (often inconvenient location)
		Analyser cabinet may require air-conditioning
Off-line on remote panel	Probe easy to remove for cleaning and calibration	Long loop time
	Convenience of having multiple analysers in a single and secure location.	Analyser room may require air-conditioning, but has economies of scale when there are multiple analysers.
		Slow sample velocities allow growth/clogging in sample lines
		Requires sample water disposal (but economies of scale if multiple analysers)
Sampled (bypass) process measurement		
Off-line on remote panel	Use of batch type analysers with reagents allows analysis of parameters that may not be practical to measure using probes.	Very long loop time
		Analyser room may require air-conditioning
		Slow sample velocities allow growth/clogging in sample lines
		Use of reagents may exclude return of the analyser output stream into the water supply. In some cases, the analyser output stream may require treatment/neutralisation prior to environmental disposal.

3.5.6.2 Mounting

Analytical instruments should generally be wall mounted. IP rating requirements are defined in section 2.1.2 of DS40-09. Since spray leaks are the relevant risk for wall-mounted equipment, instruments with less than IP65 ingress protection rating and located in a potentially wet area shall be installed within an IP65 enclosure. This provides separation of potentially wet areas from electrical control cubicles.

Where sample is taken as a bypass of the main process, the preferred arrangement is for all the accessories (pressure sustaining valve, flow gauge, etcetera) to be mounted together with the analyser on a panel (such as PVC sheet) with appropriate capture tray or trough for drips and spills.

3.5.6.3 Equipment Layout

The physical arrangement of analytical equipment needs to consider:

- Where a sample line brings a process sample to the analyser, a drain line must take the sample away after analysis. This drain line must be arranged to avoid splashing onto adjacent areas.
- If the analyser uses reagents or buffer solutions, these should be located below the analyser. They should not be located above the analyser where the chemical can leak onto the analyser. Other electrical equipment should not be mounted below sample chambers or anywhere that can result in liquid spillage (during operation or maintenance) which may damage equipment or create hazardous situations.
- Electrical cabling should be arranged so that it does not interfere with the access to any process pipework and should be protected from mechanical damage. Ducting or conduits should be used where appropriate.

3.5.6.4 Sample Water Supply

3.5.6.4.1 General

Most analysers require sample water that is free from solids. If solids are present, a strainer shall be used to prevent fouling/clogging of the sensor supply hose and sensor. Size of the strainer shall be based on the solids load, and if frequent cleaning is required, then rather than a threaded plug provide a valve and drain line to make cleaning of the strainer quick and easy. Care should be taken when a strainer is adopted for sample water to chlorine analysers because the solids accumulated in the strainer can present a significant chlorine “demand” which will interfere with accuracy of the readings. Regular cleaning of the strainer will be required.

If pressure or flow variations (e.g. from change in pressure at the sample point) will impact on the analyser operation, then a pressure regulating valve shall be included immediately upstream of the flow regulating valve.

3.5.6.4.2 Sample Flow & Pressure

Most analytical instruments will perform best when sample flow and pressure is maintained constant and within the manufacturer’s recommended range at the sensor element. This is especially true of turbidity type and amperometric type (e.g. pH & ion selective electrodes) sensors. Analyser panels shall make appropriate use of pressure sustaining valves, pressure reducing valves, flow regulating valves and manual flow control valves to achieve optimum flow and pressure conditions at the analyser sensor.

Some analysers will also have a minimum operating pressure specified. Below this pressure internal pressure/flow regulating devices may not operate correctly.

Most analysers will have a maximum pressure rating. This may require a pressure reducing valve on the sample pipework upstream of the analyser.

Pressure regulating valves shall be accompanied by a pressure gauge (upstream for pressure sustaining valves and downstream for pressure reducing valves) to allow setting and checking of the pressure.

Most analytical equipment will have a maximum or minimum (or both) limit on the flow rate through/past the sensor. Analysers that receive sample flow from a process bypass shall have a flow gauge (variable area flow meter) and throttling valve so that the sample flow rate can be set. The flow gauge shall be fitted with a low flow switch to automatically verify presence of adequate sample flow rate.

3.5.6.5 Analyser selection

In addition to the guidance in DS40-09 on analyser selection, the design shall also consider the following sub-sections.

3.5.6.5.1 Chlorine analysers

The ability of different analysers to cope with iron or manganese in the water varies considerably. Some analysers have more efficient self-cleaning mechanisms that prevent oxide products accumulating on the electrodes. Some analysers utilise very small orifices to regulate flow through the sensor, which are prone to clogging up. For the selection of analysers suitable for operation in the presence of high iron content, refer to the SCADA Approved Equipment List. Note that locating the sample point on the filter outlet (where practical) will ensure that the chlorine analyser does not receive high concentrations of iron and manganese. Where clogging occurs, a 2%w/v oxalic acid solution[9] can be used to remove iron and manganese that has accumulated on the surface of the chlorine probe and probe housing.

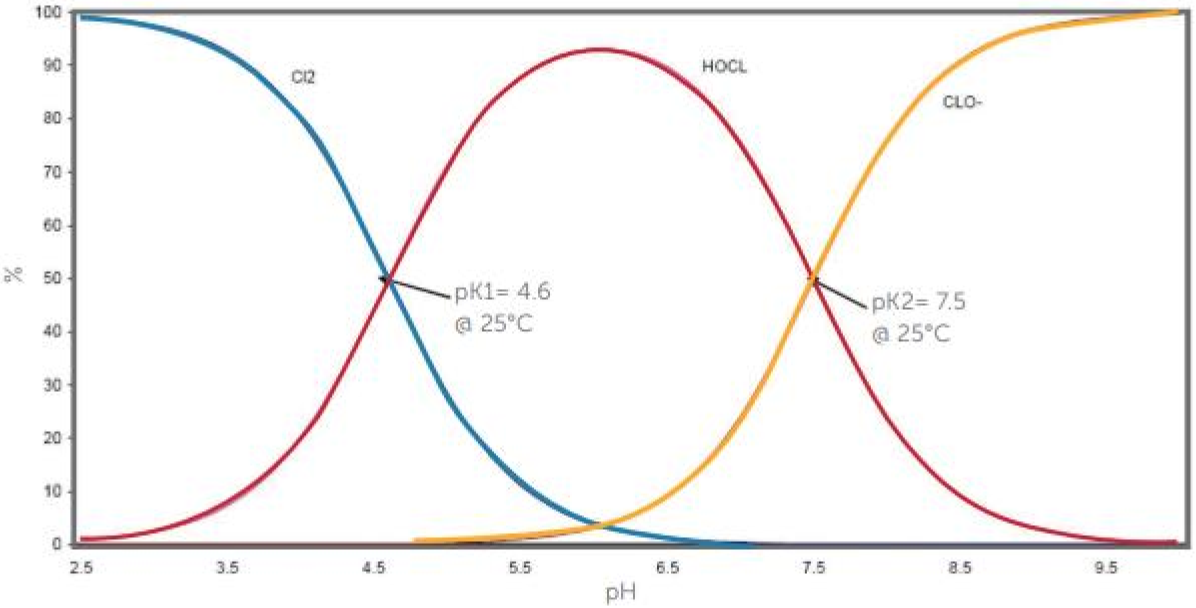

Figure 3-3: Free chlorine dissociation curve (source: HACH)

The portion of free chlorine present as hypochlorous acid (HOCl) varies with pH (refer to Figure 3-3). This has implications for disinfection performance, since hypochlorite ion is a vastly weaker disinfectant than hypochlorous acid, and also for analytical measurement. Amperometric (including so-called polarographic) free chlorine sensors directly measure only hypochlorous acid, not hypochlorite ion or chlorine. This will constrain the pH range in which reliable readings can be obtained using amperometric sensors. Use of membrane-covered, internally buffered amperometric probes can improve the accuracy of the readings. The internal buffer alters the sample pH in the immediate area of the sensor's electrode, converting hypochlorite ion to hypochlorous acid, which enables the free chlorine to be measured. Another, and complementary, strategy is to measure pH which is used for pH compensation by calculation; however, this correction factor becomes larger at high pH values, which causes large errors in the reading. The pH correction applied to an internally-buffered probe requires much smaller correction factors as compared to non-buffered samples, and thus any inaccuracy in the pH reading will have less impact on chlorine reading. The accuracy of an internally-buffered, membrane-covered, three-electrode amperometric probe with pH compensation is generally suitable for most applications. At very high pH values, consideration should be given to whether the additional capital and operating costs are

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[9] A 2% w/v oxalic acid solution is available from Rowe Scientific (product code CO0754).

worthwhile from either conditioning the sample (e.g. dosing the sample water with acetic acid to reduce pH) or using a colorimetric analyser (e.g. online DPD reagent analyser).

3.5.6.5.2 *Conductivity analysers*

As indicated in DS40-09, inductive-type analysers (also known as toroidal) are less susceptible to fouling, and therefore toroidal sensors should be selected where the possibility of precipitate build-up is likely.

3.5.6.5.3 *ORP analysers*

DS40-09 requires that manual cleaning not be required more often than every 3 months. However, rapid sensor fouling (i.e. in a couple of days) can occur in wastewater applications and similar in raw groundwater oxidation applications (e.g. Derby, weekly maintenance is required). Therefore, an automatic cleaning system will be required (refer to the ORP analyser requirements section in DS40-09 for information on types of cleaning systems that are acceptable).

3.5.6.5.4 *Turbidity analysers*

The selection and design of turbidity analysers shall be in accordance with the Turbidity Analysers section of DS40-09. For water treatment plant analysers, also refer to the “Specification for the Selection of Appropriate Turbidity Analysers (Nexus # 58583642).

3.5.6.6 Analyser output stream disposal

The sample water system can be divided into the analyser feed and the analyser bypass streams. An analyser bypass is often used to reduce the sample dead time by conveying the sample water at a high velocity to the analyser location where a portion is bled off to feed the analysers, but the remainder is returned to the process stream. Care must be taken to ensure the location of the re-entry point does not interfere with the process control system.

If the analyser output is not contaminated with reagents, then it is typically collected in a recycling tank and pumped back into the water main (non-disinfected analyser water should be returned to an upstream location where it will receive appropriate treatment, such as the head of the plant). If reagents are used, then the analyser output may not be suitable for potable use. Alternative disposal options will need to be considered; however, it is also necessary to consider whether the reagents pose an environmental risk. Options to manage environmental risk include treatment such as neutralisation, or with intransigent contaminants disposal by evaporation or collection and transport to a suitable approved offsite liquid waste facility.

Access to the sample water shall be provided for manual testing (e.g. checking calibration of the analyser). This may require a dedicated sample tap, but if the analyser does not change the composition of the sample, then the analyser output water can be used for manual sampling. Access to the analyser output water shall be provided in this case e.g. flexible tube/hose that can be removed from the drain tundish to collect a manual sample.

4 MIXING

Mixing has multiple purposes:

- achieve uniform blending of the dosed chemical into the water;
- provide mixing energy and promoting contact between particles in coagulation and flocculation; and
- keeping material suspended in the solution.

Approaches to mixing can be classified as being in-line (i.e. within the pipe) or in a mixing vessel (e.g. flocculation tank).

4.1 Mixing terminology

There are two key considerations for the designer in determining mixing requirements:

- Mixing Energy (G) – which influences the time or distance it takes to achieve mixing; and
- Coefficient of Variation (CoV) – the degree of mixing of the chemical (typically, across the radius of a pipe).

4.1.1 Mixing Energy (G)

The mixing energy concept is most commonly applied to mechanical mixers installed in a flocculation tank. Mixing objectives are often described in terms of "G value", which is a measure of the average shear or energy input applied within a mixing vessel of known volume. Effectively G is the square root of the ratio of the mixing power input to the water divided by the volume of the mixing vessel. It is widely used for flash-mixing and flocculation applications and is given by the formula:

$$G = \sqrt{\frac{P}{\mu V}}$$

where:

G = the velocity gradient (s^{-1}),

P = input mixing power (W or J/s)

μ = dynamic viscosity (Ns/m^2)

V = volume of mixing vessel (m^3) = Q x t

Q = flow (m^3/s)

t = hydraulic residence time (s)

The "G value" is used for turbulent mixing, which is of importance for coagulation where particle collision is important. Note, when mixing during flocculation, mixing is usually slow to avoid destruction of the floc.

A particular difficulty in applying the mixing energy concept to plug flow reactors (such as pipes) is estimating the volume i.e. time in which the energy is effectively dissipated. Furthermore, "G" on its own does not describe how well blended two fluids are at the end of the mixing period or vessel. Consequently, mixing objectives for chemical dosing in closed conduits (pipes) are defined in terms of the homogeneity (amount of variation in concentration) achieved within a given time or space/ distance.

4.1.2 Coefficient of Variation (CoV)

Accurate measurement of concentration by grab sample or using an online analyser requires that the chemical is well mixed at the sampling location. When two fluids (i.e. a chemical solution and the bulk water flow) are mixed in a pipe or channel, the quality of the radial mixing (across the pipe or channel) or the homogeneity of fluid mixing is defined by the Coefficient of Variation (CoV). CoV describes the deviations of local concentrations from the mean within the cross section of the pipe or channel. This is described statistically as:

$$\text{CoV} = \sigma/C$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(Ci - C)^2}{n-1}}$$

where:

σ = standard deviation (of concentration from the mean)

C = mean (average) concentration

n = number of discrete points where the concentration is measured

Lower CoV values have less deviation from the average concentration; hence, they are more uniformly mixed.

For a CoV of 0.01, this would mean that 95% of all concentration measurements (taken at a cross section) will be within ±2% of the mean concentration, and 99.75% within ±3% of the mean concentration. Table 4-1 provides a tabulation of CoV versus the distribution of mixed chemical within the receiving water. This assumes a statistical “normal distribution”.

Table 4-1 – Mixing Homogeneity versus CoV

Coefficient of Variation (CoV)	1 standard deviation 67% within	2 standard deviation 95% within	3 standard deviation 99.75% within
0.05	+/- 5%	+/-10%	+/- 15%
0.03	+/- 3%	+/- 6%	+/- 9%
0.01	+/- 1%	+/- 2%	+/- 3%

A CoV of 0.05 is described as well mixed and is often considered a reasonable target for most applications; a CoV of 0.01 is considered fully mixed. For each combination of dose point and sample point, the designer will need to select the appropriate mixing or homogeneity required for the application.

Figure 4-1 displays results from Computational Fluid Dynamic (CFD) modelling of dosing using the Water Corporation standard dosing spear design in a 1.219 m diameter pipe at a flow velocity of 0.3 m/s, which indicated that at 5 m (~ 4 D) downstream of the dose point the CoV was 0.84 (i.e. not well mixed).

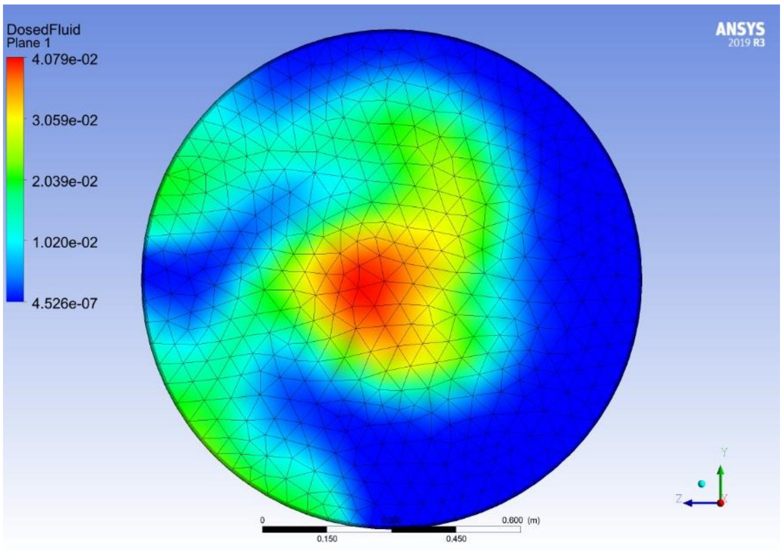


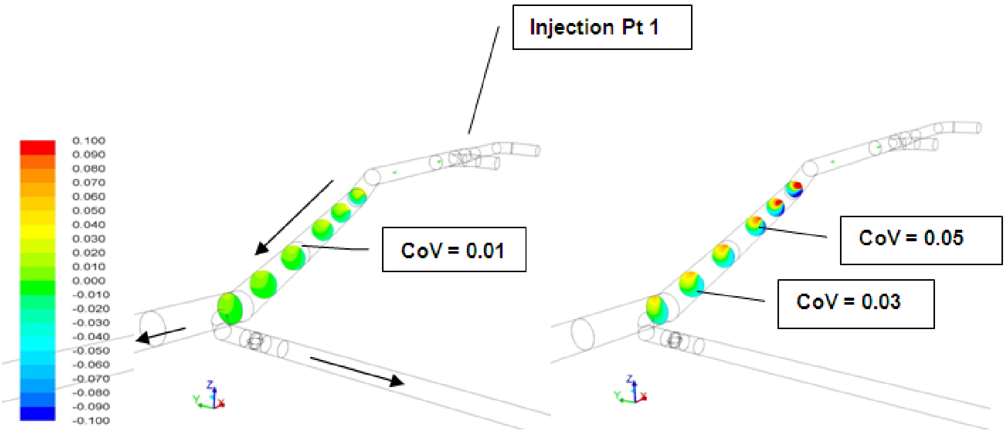
Figure 4-1: Dosing fluid concentration at 5 m downstream of DN80 - L840 spears (CoV = 0.84)

To aid the designer's understanding of CoV, the below Figure 4-2 provides CFD modelling outputs to illustrate concentration variation and CoV. Two chemical injection locations were modelled as point sources at the centreline of a 2.2 metre diameter pipe at two receiving water main flow rates. For the first location, the chemical was injected approximately 2.5 D (diameters) downstream of a combining junction from a raw water pumping station, and the second a further 5 D downstream. The CFD cross sectional images are shown at approximately 10 m (4.5 D) intervals.

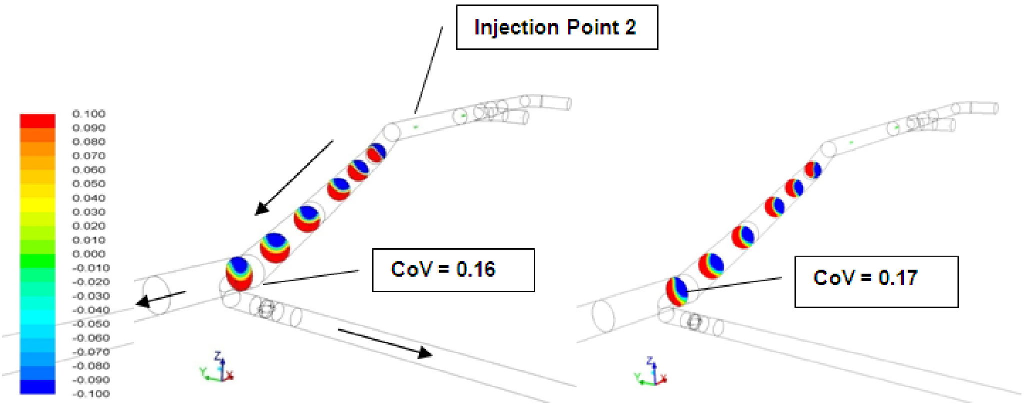
The imagery shows that despite the good (low) CoV "achieved" in the first location, there can be spatial anomalies that may be important. There is potential for local chemical distribution imbalances, which may be significant for process control, minor off-takes or sampling purposes.

The CFD modelling imagery also showed significant mixing / concentration differences between the two injection locations i.e. the turbulence immediately downstream of the junction tee (from the pump station) provided rapid mixing for the dosing at injection point 1, whereas injection point 2 was too far downstream of this turbulence to benefit from the rapid mixing.

In the second location, poor distribution is very evident (CoV= 0.16-0.17). There are also obvious and significant changes in mixing patterns with concentration gradients at the two main flow rates being vertical in one case and horizontal in the other, which would clearly impact on chemical distribution to the downstream branches. Guidance is given in section 4.3.2 on mixing lengths in straight pipe, whereas adoption of shorter lengths, such as in more complex geometries, would typically require justification using CFD modelling.



Injection Location 1: ~2.5D downstream of Y junction, 125ML/d and 250ML/d



Injection Location 2: Injection ~7.5D downstream of Y junction, 125ML/d and 250ML/d

(Concentration scale shown as +/-10% about the mean concentration.)

Figure 4-2 – CFD Model Output

4.1.3 Sampling Error

If the fluid is not well mixed when it reaches the sample point, then this compromises accurate measurement. Unless the fluid is fully mixed, then a multi-port sampling spear is necessary to collect a more representative sample. The sampling error is defined as the percentage difference between actual concentration (averaged over the pipe cross-section) and the sample concentration (average concentration at the sampling spear holes).

$$\text{Sampling error} = \frac{(\mu - \mu_{sample}) \times 100\%}{\mu}$$

Table 4-2 shows CFD results using standard dosing spear and standard sampling spear design in a straight length of DN1219 (48”) pipe at flow velocity of 0.3 m/s (1 ft/s). Assuming that sample flow is drawn equally by each port in the sampling spear and using CFD modelling of the concentration at each port, then the error between the combined sample concentration and the mean concentration is similar to the CoV. The results demonstrate how a multi-port sampling spear can partially compensate when sampling from a location where the corresponding dosed chemical is not yet completely mixed.

Table 4-2: CFD results of sample error from a multi-port sampling spear

Location	CoV	Sample Error
16.4D	29.5%	25.2%
40D	7.1%	1.1%
80D	1.7%	-0.1%

Note however that a sampling spear cannot compensate for sampling from a location where a dosed chemical is not yet completely reacted.

4.2 Mixing Requirements

Key requirements for the designer to consider:

Chemical reactions

- rapid mixing is typically necessary to avoid inefficient process outcomes, in particular for irreversible chemical reactions (e.g. in coagulation, chloramination);
- the optimal order of chemical injection and the degree of mixing required prior to addition of successive chemical(s) (e.g. for pH adjustment, buffering, chloramination, precipitation of sparingly soluble salts/ scaling); and
- time for dissolution, dissociation or nucleation.

Process monitoring and control

- the degree of mixing (uniformity of chemical concentration) required to achieve a representative sample;
- for pipeline dosing systems with feedback control, as the distance between dose point and sample point is increased, mixing is improved but the dead time of the feedback control loop increases. Excessive control loop dead time can lead to poor process control performance. These competing process design requirements must be balanced to ensure treatment objectives are consistently met. Use of ported dosing spears, inline mixers and ported sample spears can reduce the required mixing length and provide improved process control performance; and
- long sample lines and/or sample lines that flow at low velocity will similarly increase the dead time of any feedback control loop(s) which can result in poor process control performance.

Physical geometry of the system

- distance to Critical Control Points e.g. first customer off-take, regulatory compliance (measurement) point, process control points;
- distance to any downstream branches where flow is split;
- complying with any required minimum concentration-time (Ct) product for effective disinfection;
- impact on other downstream instrumentation e.g. incompletely mixed chemicals result in variations in conductivity which may impact accuracy of magnetic flow meters; and
- eliminating/ reducing corrosion risk.

4.2.1 Chemical Reactions

4.2.1.1 Strong acids/bases and chlorine

The addition and dissociation of strong inorganic acids and bases and chlorine solutions to water are classified as reversible reactions. These chemicals dissociate very quickly (typically < 1 second). The rate of mixing of the chemical, which controls the rate at which the chemical is distributed throughout the receiving water main, will therefore control the perceived rate of the reaction.

Though hydrated lime (calcium hydroxide) dissociates quickly, if dosed as slurry it will take time to dissolve in the receiving water and this will dominate over reaction time.

4.2.1.2 Weak acids/ bases

Weak acids/ bases such as carbon dioxide in solution (carbonic acid) may take of the order of a minute to become fully dissociated to bicarbonate dependent on temperature and pH conditions, and thus the reactions (though still reversible) may take longer to complete than the rate of mixing. Thus, both mixing, which controls the rate at which the chemical is distributed throughout the receiving water mains, and the time for dissociation to be completed must be considered by the designer.

Adding carbon dioxide (carbonic acid) to water	$H_2CO_3 + \leftrightarrow H^+ + HCO_3^-$

4.2.1.3 Coagulants

When fast, irreversible and competitive consecutive reactions take place, it may be necessary to achieve mixing rapidly under the appropriate chemical dosing conditions to avoid adverse outcomes. Inorganic coagulants such as ferric and aluminium salts, hydrolyse extremely quickly (< 0.3 s) and the reactions are poorly reversible. Flash mixing objectives are thus typically based on maximising chemical efficiency and achieving full mixing within 1-3 seconds. Note that after the initial rapid mixing of coagulant (to facilitate particle collision for coagulation), a prolonged period of slow mixing is required for flocculation (growth of floc).

4.2.1.4 Chloramination

Chloramination is also an area where rapid mixing can be important, and the designer must consider the specific chemicals, the pH, the order of chemical dosing and the degree of mixing before addition of the next chemical. When chlorine and ammonia mix the following reactions can take place:

Monochloramine will be formed first:	$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$
Dichloramine can then be formed from monochloramine	$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$
Trichloramine can then be formed from dichloramine	$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$

Further reactions with chlorine may proceed through to breakpoint chlorination yielding nitrate and nitrogen gas by different pathways. These reactions are irreversible. Both di-chloramine and tri-chloramine are odorous, and their formation consumes more chlorine than optimally required. The main objective in chloramination is the formation of 100% monochloramine.

The degree to which the above reactions proceed depends on the proportions of chlorine to ammonia as well as the pH. According to *White* Ref 2, the speed of conversion to monochloramine at 25°C in the presence of excess ammonia is as follows:

pH	Time seconds
2	421
4	147
7	0.2
8.3	0.069
12	33.2

At lower pH, the formation of di-chloramine is much faster, and consequently low pH should be avoided. Tri-chloramine formation will also be favoured at lower pH and high chlorine to ammonia ratio. This is an important consideration when chlorine is dosed because chlorine solution has a pH of less than 2.

The normal approach to *initial* formation of monochloramine is to dose (and ensure complete mixing of) chlorine first, then add ammonia under well mixed conditions. This order of addition normally produces disinfected water with no objectionable taste or odour.

Adding chlorine after ammonia has been added can result in excess chlorine locally near the point of injection resulting in:

- formation of di- and tri-chloramines leading to unpleasant odours (tri-chloramine is very objectionable and highly volatile)
- an increase in the amount of chlorine and ammonia required to achieve the target monochloramine residual.

Rapid mixing of chlorine is essential to mitigate the problem. The designer may also consider maintaining the pH above 7 (ideally 8 - 9) so that the dominant monochloramine will be formed rapidly before any secondary reactions can proceed.

Another alternative is to use sodium hypochlorite instead of chlorine gas because sodium hypochlorite has a high pH and the risk of di- and tri-chloramine formation is significantly reduced.

When “topping up” an existing monochloramine residual using ammonia and chlorine, it is important that ammonia is dosed first as otherwise breakpoint reactions can result in the loss of the background ammonia or objectionable taste and odour can occur due to di-chloramine and tri-chloramine formation.

4.2.2 Process Monitoring and Control

Process control involves:

- sampling and monitoring the results of adding and mixing chemical into a receiving water to achieve a desired chemical concentration or outcome; and
- based on the sample results, making appropriate adjustments to the dosing system when the outcomes are not within the required parameter range.

Effective process control requires consideration of the whole chemical system i.e. the bulk storage, handling and feed system as well as the dosing system. Important considerations in terms of the overall process control are:

- dilution of the chemical in the feed or dosing systems prior to mixing;
- the mixing time required in the receiving water;
- the dead time i.e. the time required for a sample analysis to record a process change, after the dose rate has been changed; and
- selection of an analyser with an appropriate measuring range. For example, a 0-2 mg/L free chlorine analyser will provide higher accuracy than a 0-20 mg/L analyser if the target residual concentration is 0.5 mg/L and the maximum concentration does not exceed 1 mg/L.

Water Corporation recommends that to enhance process control and for ease of tuning of instruments/analysers, a dead time of less than three minutes should be adopted as a design target with a maximum of five minutes being acceptable where achieving the three-minute target is impractical.

The designer needs to consider whether the dead time under different dose and flow conditions is appropriate for achieving control of the process, and if not, consider:

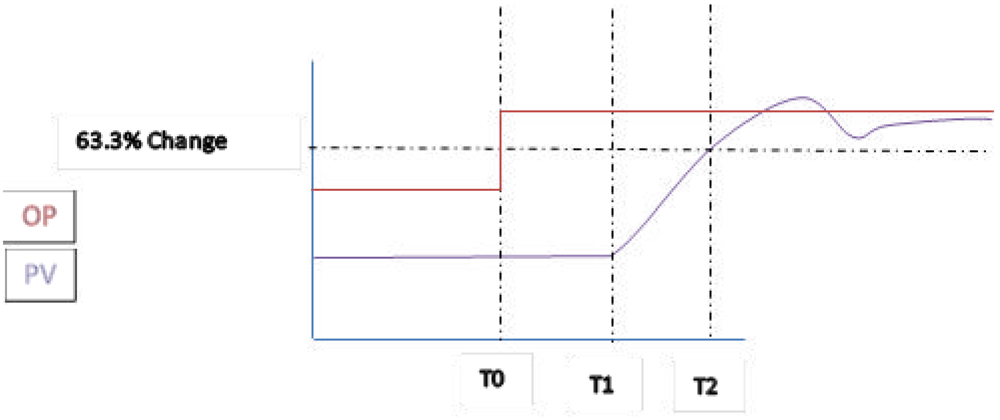
- reducing the capacity of the solution preparation tank (for dry chemical systems);
- changing a dry chemical feed system to a constant concentration system (variable flow, variable dose) or batch system;
- increasing the velocity in the dosing and/or sampling pipework (reduced travel time);
- improved mixing in the receiving water and relocation of the dose or sample point; and
- locating the analyser closer to the sample point.

For solutions that are fed at constant strength, feedback / response issues are much simpler. This applies to most bulk-delivered liquids and solutions that are prepared at constant-strength such as batched polymer or lime water systems.

If the system needs to respond quickly, there are fewer options for the designer, but these could include:

- not diluting the dosed chemical at all or only at the injection point; and
- reducing dead time (refer to above list).

For automated systems, process control can be achieved through feed-forward control (e.g. flow-paced) and/or feedback control (e.g. residual trim). The dead time is defined as the time taken to record a change in chemical concentration from the time that the dosing rate is changed i.e. $T_{dead} = (T_1 - T_0)$ as shown in Figure 4-3. This is different to lag time, which occurs after the dead time and refers to the time taken from when a change is first recorded in the measured parameter (e.g. chemical concentration) to reach 63.3% of the final chemical concentration value i.e. $T_{lag} = (T_2 - T_1)$ as shown in Figure 4-3. Lag time is typically much shorter than dead time and can be less than a second depending on the instrument and other system factors.



OP is output e.g. valve position or pump speed/stroke in the dosing system
PV is process variable e.g. pH or chemical concentration

Figure 4-3 – Dead Time (T1 – T0) & Lag Time (T2 – T1)

The following examples illustrate typical chemical dosing systems and where potential changes could be made to improve overall process monitoring and control. Figure 4-4 illustrates a dry/powder feed system such as lime (slurry) and Figure 4-5 illustrates a bulk liquid chemical feed system such as sodium hypochlorite (solution).

An important consideration is which piece of equipment (component) is to be flow-paced (and optionally feedback controlled) and which ones are to be operated at constant rate. The turndown capability of each component is an important consideration. These process design decisions are critical and have significant impact on the overall process control performance of the dosing system.

Example - Dry Chemical Feed System

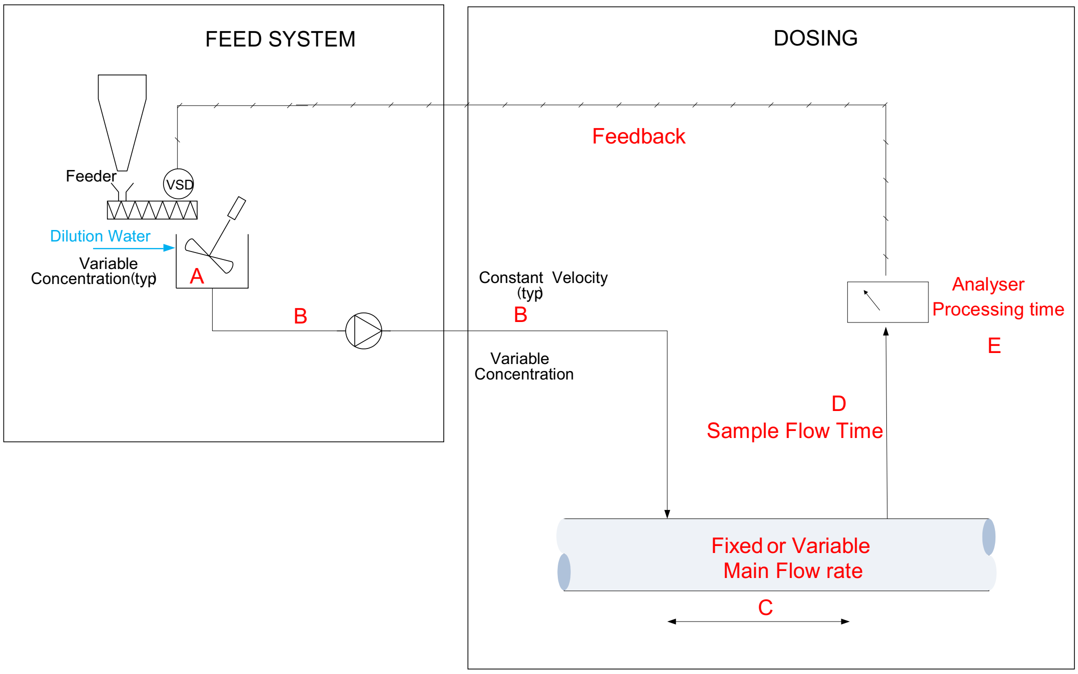


Figure 4-4 – Control Loop for Powdered System

Generally, the approach which gives the best process control outcome is for the chemical solution/slurry to be prepared on a constant strength semi-batch basis and for the dosing pump output to be the primary controlled variable.

The items shown in Figure 4-4 are described more fully as follows:

A) Dry feeders are often equipped with slurry / solution tanks that are operated with a fixed water supply rate.

> Variable tank concentration - When the main flow or feedback signal requires a change of dose at the feeder, the solution tank concentration will gradually change until it reaches the new concentration. This operates in conjunction with a fixed rate dose pump.
>
> > Advantage: Historically, dose pumps were generally limited to an automatic turn-down ratio of 1:10, whereas quite a wide turndown of batch strength is achievable subject to limitations of solubility/batch shelf-life for maximum concentration batch through to minimum batching (and any maturation) time for the minimum concentration batch strength. The advent of digital dosing pumps (with very large turn-down ratio) has overcome this turndown limitation and therefore voided the competitive advantage once held by variable batch concentration systems.
> >
> > Disadvantage: Slow loop time - The design detention time in the solution tank would typically be of the order of 5 or 10 minutes. The time for the concentration changes to be effectively complete may be 3 times the nominal detention time. Constant-flow, variable-concentration solution systems are therefore very slow to respond to changes in required dose rate or changes in flow rate in the receiving water.
>
> Constant tank concentration - A better design would utilise a constant slurry/solution makeup concentration effectively eliminating this control dead time. This would require flow control of a variable chemical dosing pump (item B).

Advantage: Minimises control loop time by eliminating detention time in the solution tank.

Disadvantage: Reducing dose rates could result in low velocities in the delivery pipeline and the settling out of solids from the slurry/solution.

B) Dosing pumps

Fixed speed (fixed dose flow rate) - Dosing pumps for constant flow variable concentration solution systems are typically fixed speed / constant piping velocity

Advantage: Simple on/off pump control. Turndown ratio of dose pumps may be limited for large dose pumps; hence, a variable batch concentration with fixed speed dose pump may be advantageous where large dose rates are required.

Disadvantage: the time for any dose response to work its way through the dosing pipework to the injection point will be directly proportional to the design velocity and pipe length. This also applies to gas feed systems.

Variable speed (variable dose flow rate) – Dosing pumps used in conjunction with a fixed concentration solution system. Some dose pumps vary stroke length rather than motor speed.

Advantage: Control loop time is minimised because changes in speed of the dose pump result in rapid propagation of the altered dose rate to the dose point.

Disadvantage: Variable dosing requires more complex control interfacing.

A better design from a process control perspective is to control the chemical dosing pump flow rate.

C) Assuming adequate mixing is achieved and all reactions are complete at the sample point, the dead time component for the main pipe is normally calculated assuming plug flow, and thus proportional to the distance between the injection point and the sample point and inversely proportional to the velocity in the main. Reducing the pipe diameter between the injection point and the sampling point has several beneficial effects. Velocity is increased, reducing dead time. Mixing is achieved in a shorter distance (although the dimensionless ratio L/D, for effective mixing, will be similar).

D) Sample flow rates to the analyser are normally constant, fixed by sample piping velocity and distance. As most analysers only require ~1L per minute of sample flow, sample line velocity may be very low resulting in significant dead time in the sample line. Locate analysers as close as is practical to the sample point. Employing a pumped sample recirculation line that is routed, at high velocity, past the analyser and then back to the water main (the analyser sample is taken from the sample recirculation line) significantly reduces this dead time.

E) Analyser response time:

Analysers such as pH, turbidity or conductivity are typically continuous and capable of almost instantaneous response. Their response is usually damped.

Other analysers such as multiparameter or alkalinity analysers may utilise batch type analysis methods (e.g. Chemscan® chloramination process analyser). Such batch type analysers only update their output according to a pre-set interval which will have a minimum value of typically 2-10 minutes depending on instrument (e.g. the shortest sample interval for the Chemscan® chloramination process analyser is 10 minutes). This is effectively another component of the control loop dead time and must be factored into the process control design and tuning.

Example - Liquid Chemical Feed System

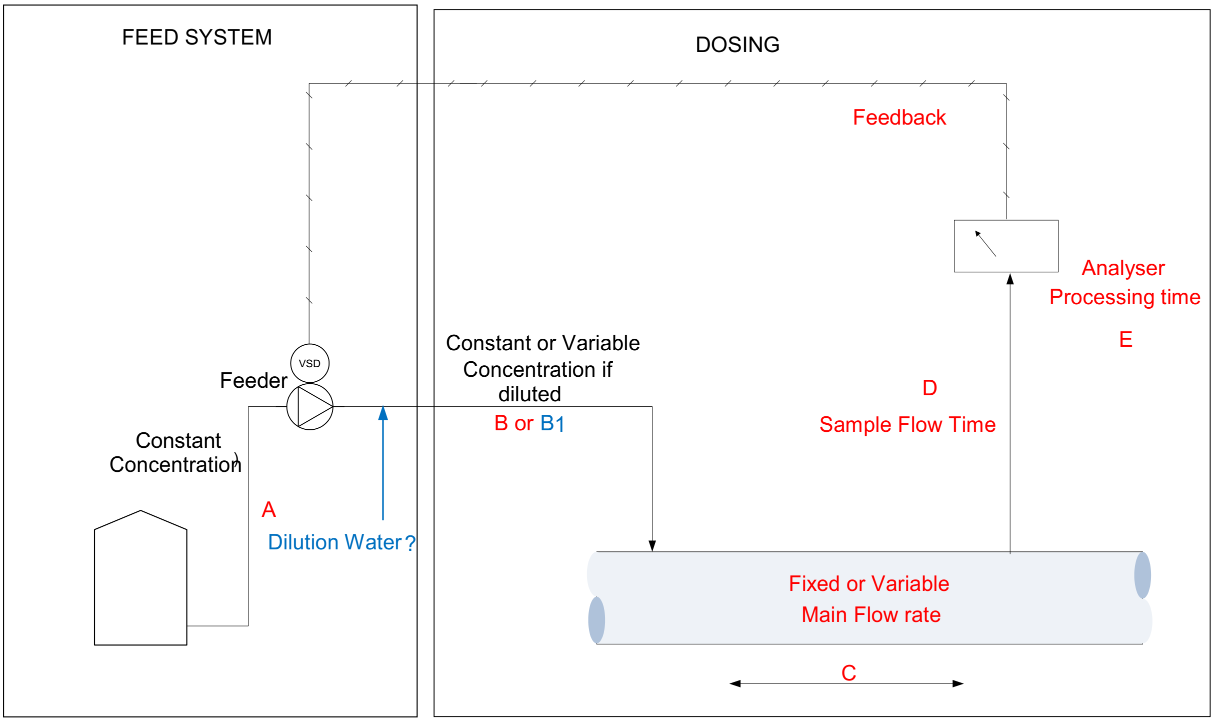


Figure 4-5 – Control Loop for Liquid Chemical System

The items shown in Figure 4-5 are described more fully below.

A, B) For dosing pumps that are variable speed (variable dose flow rate) the response to a flow or feedback change request is effectively instantaneous through to the point of dilution.

B1) If the chemical is diluted before the injection point and the dilution flow is large relative to the chemical flow in the pipe, then flow tends to constant velocity and the loop response component will be inversely proportional to the design velocity and pipe length.

Mixing dose and dilution water at dose panel

Advantage: Simplicity of a single dose pipe. Safety advantage from dilute chemical. Also, dilute chemical may be less prone to freezing, avoiding the need for heat tracing and insulation.

Disadvantages: Refer to section 2.2.5 for scaling problems and refer to section 2.2.9 for reactions with dilution water that affect the dose efficiency.

Mixing dose and dilution water just before dose point

Advantage: Minimises control loop time. This also minimises time/opportunity for undesirable reactions between chemical and dilution water (e.g. scale formation or coagulant/polyelectrolyte reacting with dilution water, refer to section 3.3.5).

Disadvantage: Complexity of two pipes rather than a single pipe. Also, the concentrated chemical generally poses higher safety and environmental risk compared to after dilution.

C, D, E) Receiving water pipe, sample transit times and analyser response times are the same as in the previous example for a powdered system.

4.2.3 Physical Geometry of the System

The designer must determine the degree of mixing required considering the physical characteristics of the receiving mains as well as any process and control requirements.

Process monitoring and control requirements include:

- the need for a representative sample; and
- the loop times for control purposes.

Mixing requirements may be driven by the physical geometry of the system such as:

- flow meter type and position;
- limitations on availability of above ground dosing points and required manifold length on the receiving main;
- corrosion considerations; and
- distance to downstream branches and customer off-takes.

The mixing requirements before major pipe branches and customer offtakes may differ, particularly for large branches within a treatment plant or distribution system. For a large branch downstream of a chemical injection point, the mixing requirement might only be to ensure that the branch receives an equal average concentration of the chemical and not necessarily that the chemical is well mixed. Conversely for a small branch or customer off-take, which receives only a very small proportion of the main flow, it will be critical that the injected chemical is well mixed, otherwise the off-take may receive a disproportionate amount of the dosed chemical, or the chemical concentration may fluctuate (unacceptably) with time.

For example, to achieve very good mixing, with a CoV of 0.01, may require a length of pipe of over 200 D, assuming a smooth, larger diameter pipe with a simple wall injection point. This length could reduce by 30-40% if the target CoV were to be only 0.05. A CoV of 0.01 may therefore be appropriate for first customers, and a CoV of 0.05 acceptable at major branches.

The need for a representative sample for monitoring, control and compliance purposes is clearly important and an understanding of the system flow and mixing characteristics is required. If the chemical has not adequately mixed by the time the sample point is reached, then this could result in the sample being unrepresentative through:

- drawing from an area which is consistently higher or lower than the average chemical concentration; or
- chemical concentration and hence sample analysis results fluctuating wildly, making the analyser output (process variable) inappropriate for control or monitoring purposes.

4.2.3.1 Corrosion

Minimising corrosion can be a factor driving the need for better mixing. Targeting a short mixing distance for potentially corrosive chemicals should be considered if this will reduce risk of premature pipe failure and/or enable a more cost-effective choice/ reduce the required extent of special corrosion resistant materials.

The design of chemical injection points and subsequent downstream mixing should aim to ensure that corrosive chemicals are well mixed in the bulk flow before reaching the pipe wall. Where this is not practical then a suitable length of pipe that is resistant to corrosion from the dosed chemical shall be provided at and downstream of the chemical injection point.

4.2.3.2 Flow Meters

Some flow meters such as magnetic flow meters are prone to erratic behaviour when located within the mixing zone downstream of a chemical dosing point. Where the location and choice of flow meter cannot be altered, both mixing effectiveness and reaction completion will be required well upstream of the flow meter. Alternatives to consider are:

- change location of the dosing point to be downstream of the flow meter; or

- select a type of mixer that can achieve full mixing prior to the magflow; or
- change to a different type of flow meter (whose measurement principle is not impacted by fluctuations in conductivity of the dosed water).

4.3 MIXER SELECTION

4.3.1 Outline of Mixing and Injection Types

There are a broad variety of methods and equipment options for the continuous injection of chemical fluids in water pipelines to achieve objectives in mixing, dispersion, and reaction. Irrespective of the method of mixing, energy is required to achieve the desired result. Options available to the designer to achieve the mixing objectives include:

- pipeline turbulence only (e.g. tapping point at the pipe wall with dose line connected);
- turbulence from in-line pipe fittings (e.g. elbows), restrictions (e.g. valves) and/or a section of reduced line diameter, and similar;
- dosing quill that extends part-way into the line being dosed;
- dosing spear(s) /multi-port dosing diffuser(s);
- static (motionless) mixers;
- in-line mechanical mixers;
- jet mixers (tee); and
- high volume jet mix (in pipe).

4.3.1.1 Pipeline Mixing Only

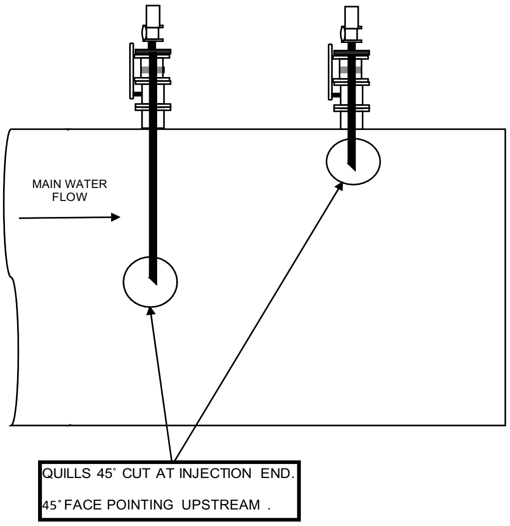
Chemical is injected at the pipeline wall, and mixing is achieved by a combination of diffusion and the turbulence generated by pipe friction. There is no applied energy and mixing is typically slow, with good mixing being accomplished over a long distance.

4.3.1.2 Inline Pipe Fittings, Restrictions, Valves etc.

These generate localised turbulence, reducing the line length required for effective mixing.

4.3.1.3 Dosing Quills

Chemical injection quills are single-point injection devices, inserted through the wall of the receiving pipeline. Quills are typically used to introduce medium to highly corrosive chemicals into a pipeline without damage to the side port or pipe wall at the point of injection. They often have a bevel face. The location of the quill tip dictates whether they are more similar to a wall source or a central source.



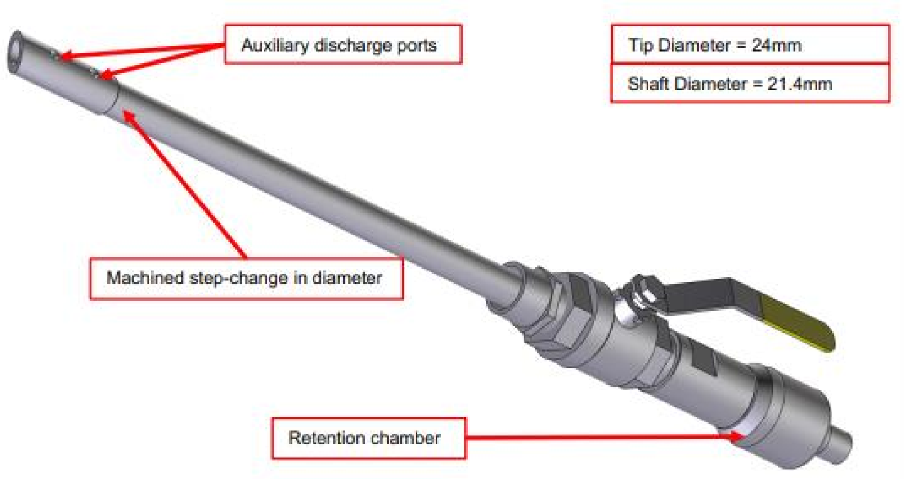


Figure 4-6 – Dosing Quill Schematic (Trility/Hydramet HQ3 injection quill)

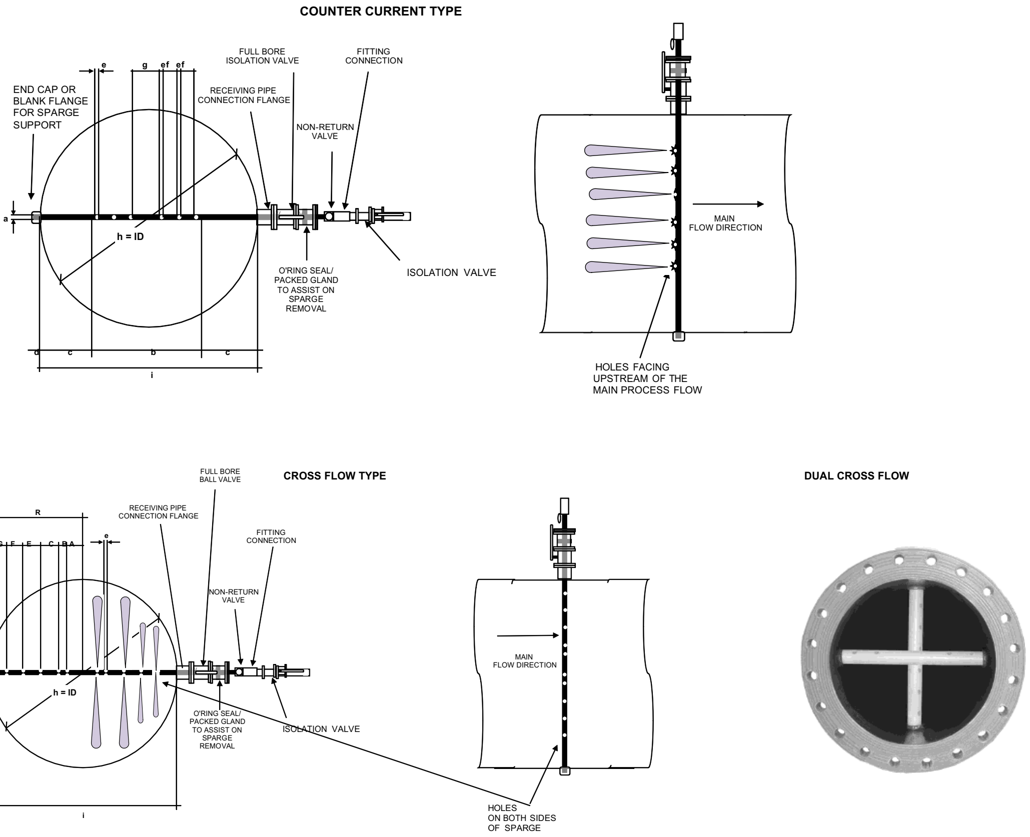
Quills may be selected to inject fluid a short distance away from the side wall (1/8 to 1/3 D), or at the centre-line (0.5 D). Use of chemical injection quills prevents risk of pipe corrosion due to channeling the chemical along the pipe wall.

If quills need to be withdrawn while the main is in service, they can be supplied in retractable form (e.g. the Hydramet HQ3 injection quill). Limitations on quill length are discussed in section 3.5.4.5.2.

For materials selection guidance, please refer to section 3.5.4.5.1.

4.3.1.4 Spears

Spears are perforated pipes, sometimes called diffusers or spargers. They comprise an insertion pipe with multiple orifices through which chemicals are injected in a distributed fashion into the receiving water pipe. Spears with a single line of orifices that inject upstream are termed counter flow, and spears with two lines of orifices that inject fluid across the main flow towards wall of the recipient water main are termed cross flow. They can be of single or dual configuration. Orifices should be at least 3.5 mm diameter to minimise risk of scaling. Selection of dilution water flow rate and orifice size shall be to inject fluid at high velocity (typically 5 m/s; for a diffuser with larger orifices then 6-to 9 m/s may have reasonable headloss) to achieve relatively fast mixing.



Source: InyoProcess

Figure 4-7 – Dosing Spear Schematic

As with quills, there are a variety of types. Long spears may also deflect and bend under high water main velocities or vibrate due to vortices. Long spears are therefore typically supported/ or "potted" into the other side of the main pipe. The Water Corporation's standard design for dosing and sampling spears has factored in constraints such as vortex induced vibration (VIV) on unsupported (cantilevered) spears. The maximum unsupported length to avoid the onset of VIV was 810 mm for a DN65 schedule 80S spear. For pipelines up to DN800, the preferred equal area segment approach could be achieved with spear length and hole spacing sized accordingly. For pipelines DN900 to DN1200, the maximum spear length of 810 mm was employed.

For materials selection guidance, please refer to section 3.5.4.5.1.

4.3.1.5 Static (Motionless) Mixers

Motionless mixers have a series of internal baffles or vanes that achieve mixing turbulence via splitting, rotating and recombining flows as well as generation of trailing vortices. Newer, motionless mixers rely solely on vortex generation to get equivalent blending results.

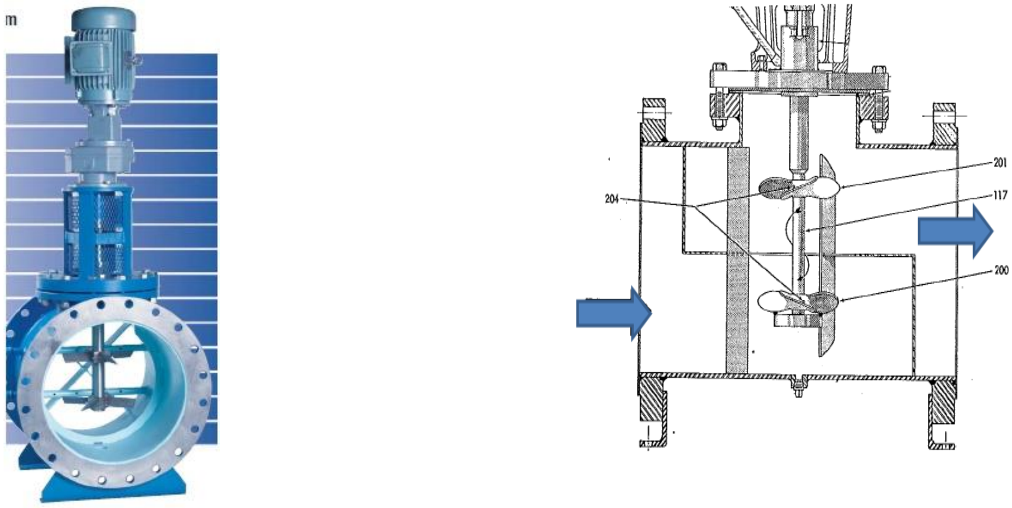
Source: Koflo

Figure 4-8 – Static Mixer

4.3.1.6 In-Line Mechanical Blenders

In-line, high-shear, rotor–stator mixer / blenders are motor-driven, radial-impeller rotors, with the impeller typically contained in a flanged pipe housing. The impellers are high shear and may contain internal baffles / stators or spears for optimum efficiency. The mixing energy inputs required for these types of mixers are very high. They are also high maintenance.

Since they are high maintenance, in-line mechanical blender mixers are rarely used in municipal water treatment and are not recommended for use.



Full flow type
http://www.haywardgordon.com/documents/HG_Dynamic_In-Line.pdf

Internally baffled type
Source: Lightnin

Figure 4-9 – In-Line Mechanical Blenders

4.3.1.7 Jet (Tee) Mixers

Jet mixers inject water at high velocity to create mixing energy and dispersion of the injected chemical into the receiving water flow. These are also sometimes referred to as Tee Mixers. Variations include 90-degree side-tee, inclined and multi-jet arrangements.

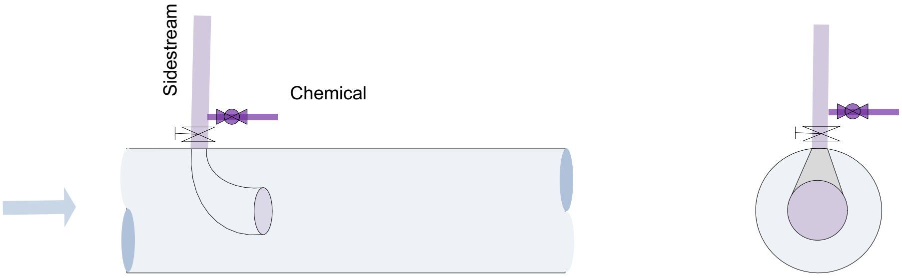


Figure 4-10 – Jet (Tee) Mixer

These types of mixers are often useful in that scaling or corrosive chemicals can be injected into, or very close to, the free jet as it enters the receiving main, and thus minimise scaling or corrosion risks by design.

If the injected flow rate and main flow rate are not optimised by design as well as in operation, they will deliver a non-uniform chemical distribution as the degree of jet penetration is proportional to the momentum of both the injected and the receiving water flow streams.

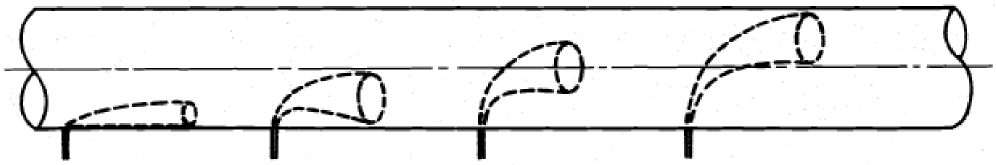


Figure 4-11 – Chemical distribution proportional to momentum of injected and receiving streams

Multi-jet designs can overcome non uniform distribution but can be complex to operate if each injection tee requires a separate chemical injection point (Reference 7).

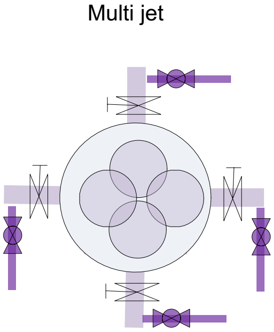


Figure 4-12 – Multi-Jet (Tee) Mixer

4.3.1.8 Jet Mixers (In-Pipe)

In-pipe jet mixing typically involves the injection of relatively high volumes of water at high velocity and often has dedicated mixing water supply pumps. They are sometimes referred to as pump jet mixers. Water is typically injected in a symmetrical fashion about the centre-line of the pipe and therefore mixing is uniformly distributed.

Impingement and nozzle types may be configured with the chemical injected into, or very close to, the free jet as it enters the receiving water, thus avoiding scaling and corrosion issues in the dosing pipework (as for low-volume Tee Jet Mixers). These types of mixers are high energy and have mostly been used in coagulant flash mixing applications.

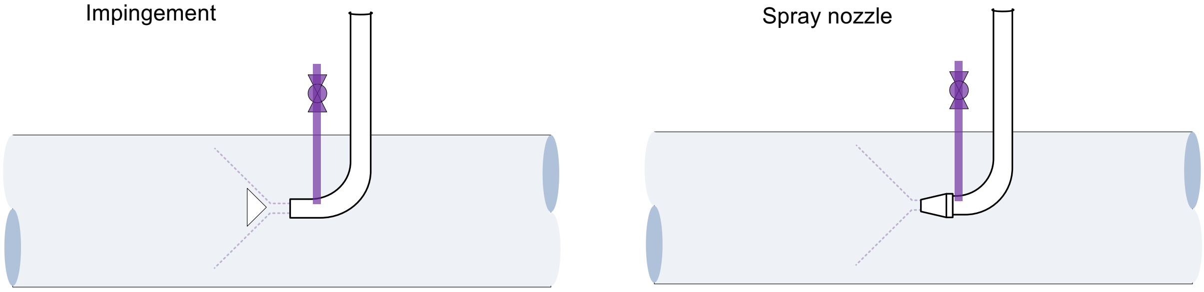
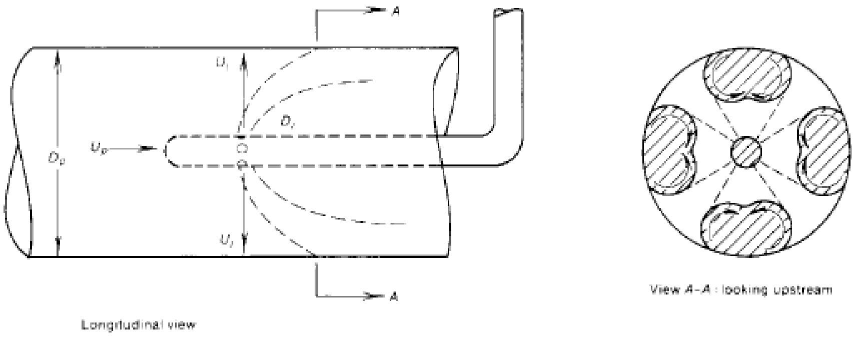


Figure 4-13 – In-Pipe Jet Mixer

Other variants can achieve good mixing distribution but are not suited to potentially scaling chemicals.

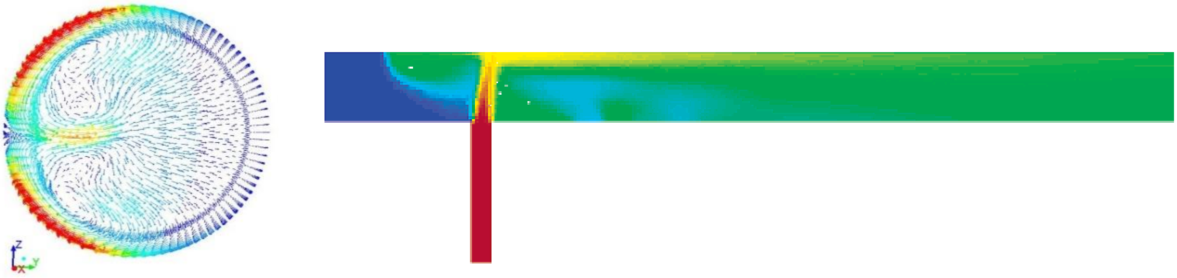


Source: Reference 9

Figure 4-14 – Multi-Jet (In-Pipe) Mixe

4.3.1.9 Secondary Flow Mixing

In some cases, it is possible to take advantage of strong secondary (internal radial flow patterns) to enhance chemical dispersion at sharp bends or joining tees.



Source: Reference 10

Figure 4-15 – Secondary Flow Mixing

Mixing effectiveness is highly dependent on geometry and flow conditions.

4.3.2 Mixer Selection

4.3.2.1 Mixer Selection Hierarchy

The application of DS78 applies to receiving water pipes typically with:

- a diameter in the range of 0.1m to about 1.8 m;

- a velocity in the range of 0.1 m/s up to 3 m/s; and
- a corresponding Reynolds Number in the range of $1x10^4$ to $6x10^6$.

For fully turbulent flow (Reynolds No > 10,000) and if there are no process control response time or distance constraints then simple turbulent mixing in a long length of pipe can offer acceptable mixing and may be the best choice.

The initial system assessment of mixing requirements should take into account whether carrier or dilution water is inherent to the delivery of the chemical to the injection point, for example where water is required to dose gases in solution (chlorine gas, anhydrous ammonia, etc.), slurries, or where mandatory for safety reasons (e.g. FSA).

If there is insufficient natural mixing in the available distance / time, then the energy or time for mixing must be increased by altering the system configuration, using energy available in the main water flow, or providing supplemental energy.

Options for selecting the best mixer or mixing method can be grouped into four broad categories:

1. **Opportunity from the inherent pipeline energy and the specific physical configuration:**
   - providing more separation by relocating the chemical injection points up stream and/or sample points further downstream;
   - increasing the pipe “length” by taking a more circuitous route;
   - decreasing the pipe diameter (the ratio L/D to achieve mixing will be similar, but at smaller D this means L will be smaller i.e. mixing is achieved in a shorter pipe length and with less dead time);
   - changing from side wall injection to a central quill;
   - dosing in an area where high mixing energy is available e.g. Injecting into the extra turbulence near a control valve, elbow or tee or at the suction side of pumps; and
   - modifying the sampling arrangement for example from quill to a spear configuration.

2. **Where dilution water is inherent to the system design:**
   - changing from wall injection to a central quill;
   - changing from quill to spear; and
   - increasing dilution water flow.

3. **Where there is sufficient “spare” hydraulic energy available in the receiving water:**
   - static/ motionless mixers.

4. **Where external energy is required to provide extra mixing then there are several options available to the designer including:**
   - providing carrier water and spear mixing in various configurations;
   - hydraulic jet mixing (tee or in-pipe); and
   - in-line mechanical mixers (note: this is the least preferred option and should be avoided if possible).

The designer must recognise in assessing the appropriate mixing type that safety, simplicity, reliability, low O&M cost and achieving good process control outcomes are key considerations.

The mixing distance (to achieve mixing across the full cross-section) is directly proportional to the radial distance that the dosed chemical needs to spread. This is why the dimensionless ratio L/D is commonly used as the measure of mixing distance required.

Table 4-3 – Relationship between Dosing Arrangement and Mixing Length

Radial Distance	Mixing Length	Dosing Arrangement	Comment
Reducing ↓	Reducing ↓	Wall injection	Dosing at the pipe wall will result in the longest radial distance (i.e. the whole diameter) that the chemical needs to mix.
		Quill	Dosing at the pipe centre will result in half the radial distance for mixing compared to dosing at the pipe wall. This substantially reduces the pipe length required to achieve full mixing.
		1 x Spear	Dosing with a multi-port spear further reduces the radial distance for mixing compared to a quill. The orifices in the spear are spaced to divide the pipe into equal area segments.
		2 x Spears	Dosing with two multi-port spears (arranged perpendicular to each other) further reduces the radial distance for mixing compared to a single spear.

Table 4-4 (below) gives a general guide to initial selection of mixer types that may be suitable. Mixing distances were based on CFD modelling (refer to Nexus document #130433878) for dosing 1 mg/L of FSA as representative of a typical dosing scenario. The assumed injection velocity was based on the dosed chemical being diluted with solution water at a 20:1 ratio for the maximum dose rate (i.e. minimum dilution of 20:1). The CFD modelling used a structured mesh to reduce computational time; however, this results in the CFD modelling being conservative (see comparison in Figure 4-16). Therefore, if the available mixing distance is less than but within 30% of the CFD modelling results in Table 4-4, then dispensation may be sought from the Senior Principal Engineer – Water Treatment on whether the available mixing distance is sufficient.

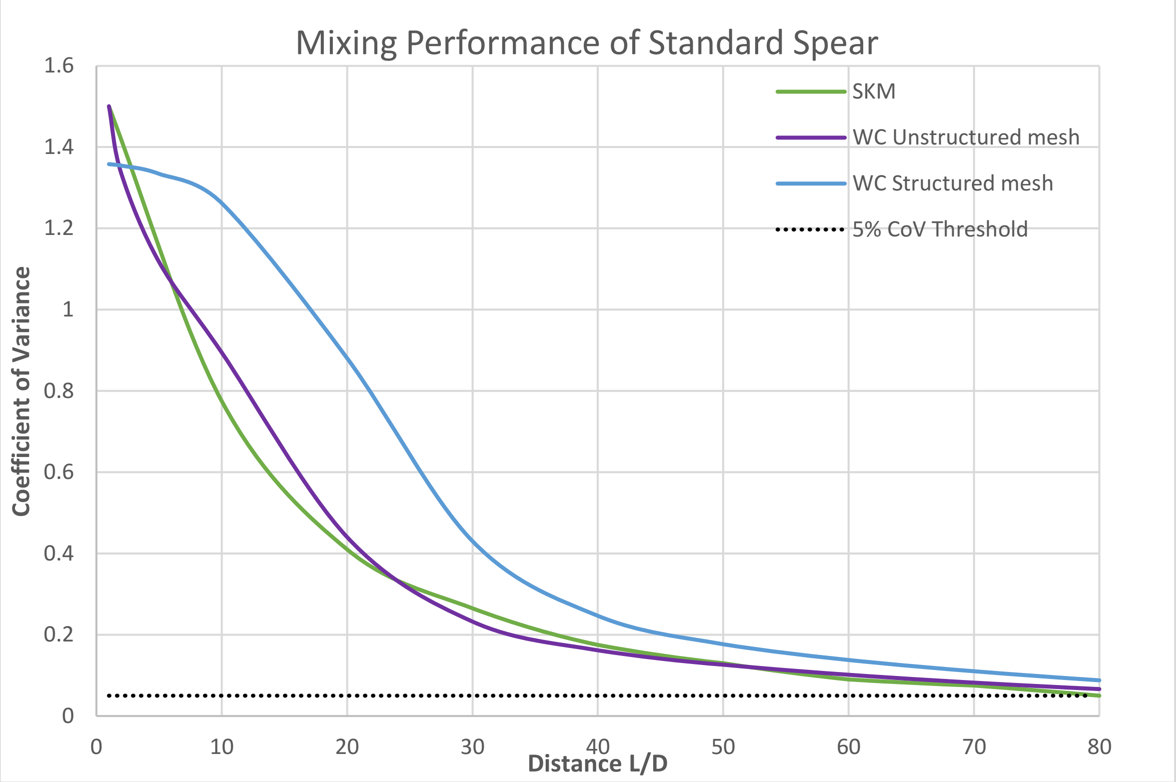
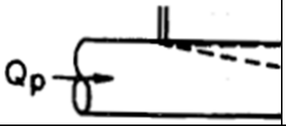
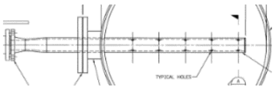
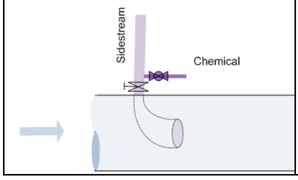


Figure 4-16: CFD modelling comparison with and without structured mesh

Table 4-4 – Guide to Selection of Mixer Type

Dosing Spear / Diffuser Arrangement	Features Between Dosing & Sample Point	Sample Spear Arrangement	Minimum Distance (as L/D) Between Dose & Sample Points			
Wall Injection 	None - Straight Pipe Run	None - Sample taken from nipple or spigot on pipe wall.	Bulk velocity	DN100	DN300	
			0.1 m/s	115	145	
			1.0 m/s	135	175	
			3.0 m/s	140	180	
Quill (D/2 from wall) Source: Trility	None - Straight Pipe Run	None - Sample taken from nipple or spigot on pipe wall.	Bulk velocity	DN100	DN300	DN600
			0.1 m/s	80	115	105
			1.0 m/s	30	130	100
			3.0 m/s	30	135	110
		Single port sampling spear 1/3D to 1/2D insertion	Bulk velocity	DN100	DN300	DN600
			0.1 m/s	65	115	100
			1.0 m/s	30	125	85
			3.0 m/s	30	115	100
1x multiple port spear (>=2/3D insertion) 	None - Straight Pipe Run	Single port sampling spear 1/3D to 1/2D insertion	Bulk velocity	DN100	DN300	DN600
			0.1 m/s	5	5	10
			1.0 m/s	20	50	65
			3.0 m/s	95	55	70
		1x Multiple port sample spear with >= 2/3D insertion.	Bulk velocity	DN100	DN300	DN600
			0.1 m/s	5	5	10
			1.0 m/s	25	50	60
			3.0 m/s	30	55	60
2x multiple port spears (both duty) each with >= 2/3D insertion	None - Straight Pipe Run	1x Multiple port sample spear with >= 2/3D insertion.	Bulk velocity	DN100	DN300	DN600
			0.1 m/s	5	5	5
			1.0 m/s	20	40	45
			3.0 m/s	20	50	50
2x multiple port spears (both duty) as per standard design	None - Straight Pipe Run	1x Multiple port sample spear	Bulk velocity	DN1200		
			0.1 m/s	60		
			0.3 m/s	95		
			1.0 m/s	100		
			3.0 m/s	115		
2x multiple port spears (both duty) as per standard design plus two extra holes in end of spear	None - Straight Pipe Run	1x Multiple port sample spear	Bulk velocity	DN1200		
			0.1 m/s	8		
			0.3 m/s	53		
			1.0 m/s	77		
			3.0 m/s	76		
Single port dosing spear 1/3D to 1/2D insertion	Static Mixer  Source: koflo	Any	Typically ~5 (i.e. 5D). Refer to Mixer manufacturer's requirements.			
Tee Jet 	None - Straight Pipe Run	None - Sample taken from nipple or spigot on pipe wall.	Bulk velocity	DN100	DN300	
			0.1 m/s	115	145	
			1.0 m/s	135	175	
			3.0 m/s	140	185	

The DN1200 Water Corporation standard dosing spears are limited in length to minimise vortex induced vibration. Unfortunately, this leads to sub-optimal mixing as the equal area mixing design intent is not achieved. For large diameter pipes (with half-diameter spears), improvement in performance can be achieved by drilling two extra holes in the spear end caps (which increases the spread of the dosed chemical over a larger cross-section of the pipe) together with additional dilution water flow to maintain the same discharge velocity through each hole (refer to example for DN1200 pipe in Table 4-4 above). If the spear design is to include the two extra holes, then the hole size must be adjusted to achieve the target average velocity through the holes. The designer should take this into account in their hydraulic design and allow for the relevant head loss.

4.3.2.2 Key Selection Considerations

As well as mixing, key mixer selection issues are provided in Table 4-5 below and need to be considered in the context of:

- site location;
- installation location (above or below ground);
- access to dosing points and mixers for maintenance and general operation;
- frequency of attendance for operations and maintenance;
- level of automation and remote monitoring; and
- whole-of-life costs.

Table 4-5 – Mixer Selection Considerations

Considerations	Issues	Remark
Chemical Characteristics		
Alkaline chemicals reacting with calcium (or magnesium) in receiving water) Calcium chemicals with carbonate/ bicarbonates in receiving water	Scaling	All injections points and spears at risk. Consider elastomeric quill tips, inbuilt check valves. Redundant quills / spears and retractable designs may be required.
Concentrated mineral acids and alkalis especially sulphuric acid mixing in receiving water	Heat rise/ change of phase	
Acids	Corrosion	Chemicals with high specific gravity may change fluid mixing assumptions. Special corrosion resistant materials may be required locally (e.g. mixing tees).
Coagulants / flocculants	Fouling	Require rapid initial mixing followed by low or tapered mixing energy. Spears and fine nozzles can shear flocculants and are therefore unsuitable.
Process Control		
Length of pipe and line velocity between injected chemicals and sampling point	Loop response	Higher velocity flow and designs that provide reduced mixing length between the injection and sampling point will have lower open loop response time and therefore will allow better control. Consider impact of the reduction of line diameter on distance required to achieve effective mixing.
Hydraulic Conditions		
Variability of main water flow rate	Mixer Effectiveness	Mixing energy for static mixers decreases at lower flows (mixing time and distance increase to achieve the same mixing objective); May result in significantly different mixing outcomes for cross flow jet mixers optimised for specific main flow velocities
System pressure	Safety	Retractable spears require special consideration as ejection force can be considerable.
Scale		
Conduit size/ characteristics		Small systems favour pipeline mixing. A high Reynolds number increases the number of pipe diameters to achieve equivalent homogeneity. Mixing effectiveness and practicality of quills and spears decreases at larger diameters.
Installation		
Below ground location	Serviceability, Confined spaces	Significant issue for all mixing devices, in line blenders less favoured.
Isolation and / or bypass requirements	Maintenance requirements, Cost	Need to shut down main water to service mixing equipment. Consider for all systems or devices. Significant issue for static mixers and in-line blenders especially for large pipes.
Need for lifting / craneage for servicing / repairs	Maintenance requirements, Cost	Significant issue for static mixers and in-line blenders especially for large pipes.
Opex		
Energy required		In-line blenders are typically the most energy intensive. Use of available hydraulic energy is a preferred approach.
Mechanical maintenance	O & M	Not desirable in remote areas
Specialised Servicing or unique parts	O & M	Not desirable in remote areas

4.3.3 Quills

4.3.3.1 Mixing Performance

Unless chemicals are injected with high velocity (and momentum) into the receiving water flow, dosed chemicals may be assumed to have similar mixing characteristics to a simple wall source.

Single point wall sources are asymmetric and - to obtain a CoV in the range of 0.01 to 0.1 - require approximately 2.5 to 3 times the mixing length compared to injecting chemical at the centre of the pipe. In Figure 4-17, *Fitzgerald & Holley* (Ref 7) summarised CoV versus mixing distance Z for different points of injection within the fluid. (Note that Z is not explicitly length / diameter, and *ρ'* is the dimensionless radial distance from the centre-line to the wall of the pipe).

What is of note is the dramatic fall off in mixing efficiency away from centre-line injection. Even an injection point 1/3 D from the wall (*ρ'* = 0.33) as typically recommended by quill manufacturers' will require twice the length to achieve the same degree of mixing as for a chemical injected at the centre-line of the fluid.

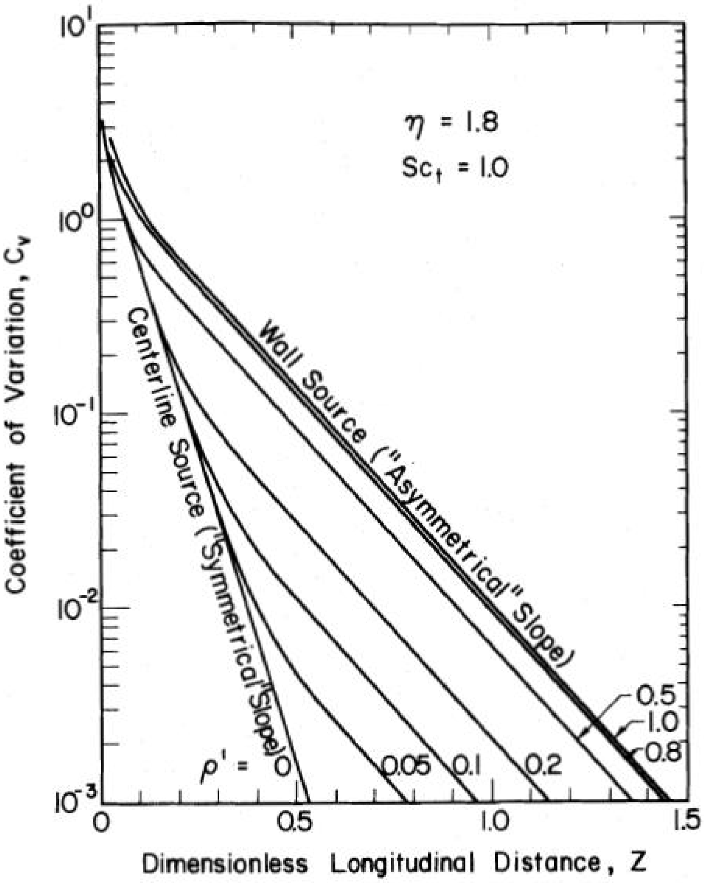


Figure 4-17 – CoV versus (dimensionless) Mixing Distance

According the Handbook of Industrial Mixing (Ref 1) the mixing distance for centre-line injection can be defined by:

$$\frac{L}{D}_{\text{mix}} = 20.5\text{Re}^{0.10}\left(\frac{f_s}{f}\right)^{0.5}\log(2.40\ \text{CoV})$$

For central injection into a smooth pipe, the required mixing length for different Reynolds numbers and mixing efficiencies are summarised in Table 4-6 below.

Table 4-6 – Required L/D for smooth pipes for various CoV targets

	Reynolds Number			
CoV	**10,000**	**100,000**	**1,000,000**	**6,000,000**
0.05	48	60	76	95
0.03	59	75	94	112
0.01	84	106	133	159

For wall injection, the mixing lengths required will be of the order of three times the above. Of note is that the mixing length to achieve a target CoV increases at higher Reynolds numbers.

It is expected that an injection device (e.g. quill) will in normal circumstances contribute to mixing benefit, particularly in smaller pipes, as the insert, and in particular the tip, will generate some trailing vortices. The designer must also consider other factors that may increase mixing length, especially for central mixing, such as:

- inaccurate central "positioning" of the quill;
- the effects of the injection velocity carrying fluid away from the centre-line;
- any differential density between the dosing and receiving fluids; and
- distorted receiving water velocity profile due to upstream bends and fittings.

4.3.3.2 Installation and Design

Dosing quills are typically used for small chemical injection flows / smaller pipelines or on larger pipelines if mixing time / distance is not critical. Before adopting a quill, the designer should consider whether a formal quill is necessary, for example, where corrosion or scaling is unlikely.

Where there is a need for injection within the body of the receiving water, the quill design shall consider the receiving water flow and characteristics, as well as any chemical reaction issues at the interface between the chemical and the receiving water.

Quills are available in multiple configurations and materials. The designer needs to consider the following factors related to quills.

Receiving Water Pressure

If the quill is to be withdrawn or maintained while the receiving water is charged and at line pressure, it will need to be a retractable design, and designed so that it can be removed safely. Minimising the diameter of the quill can considerably reduce the force, and safety issues associated with withdrawing a quill. An adequate restraint system and choice of material for the solution tube are critical to the safe operation of this unit.

The restraint system must be capable of holding the quill securely in place when subject to maximum system pressure and / or surge conditions and enable controlled withdrawal of the quill for maintenance. The restraint system must have a pressure rating and margin of safety over the maximum operating pressure.

A non-retractable injection quill cannot be removed from a pressurised water main. The main must be isolated, pressure relieved and water drained to a level below the injection quill before its removal from the water main. This must be acceptable as the basis of design.

Receiving Water Velocity

High fluid velocity causes flex and vibration, which may lead to failure of quills due to bending or fatigue, especially with plastic quills, for which typical recommended maximum insertion depths are 150 mm for a 25 mm quill. Where velocities are above 1.5 to 1.8 m/s, plastic quills may not be appropriate because of the risk of failure. The designer should also consider the presence of upstream fittings, which may cause local higher velocities. Deformation is also a common problem with retraction of a deformed quill potentially extremely difficult.

Where greater insertion depths are proposed or the receiving water velocity is anticipated to be high, selection of corrosion-resistant metals or plastic-coated metals will need to be considered. The length of cantilevered quills is also subject to limitation in large pipelines. For pipelines DN600 and larger the use of cantilevered injection quills or spears (this has already been done for the Water Corporation standard design dosing spear) shall be subject to the designer completing a check for Vortex Induced Vibration (VIV) and the resulting potential for fatigue failure of the quill. This design check shall be completed for the proposed installation detail and cover the range of line velocities expected and shall factor in nearby pipe features that impact the flow pattern at the quill or spear.

Quill Injection Tip Location

The quill injection tip should be located close to the centreline of the receiving pipe for optimal mixing. The designer must also consider fluid properties (density) and corrosion before finalising the location.

Tip Design

To enhance mixing, the quill tip should be beveled at 45 degrees and facing upstream.

Scaling Considerations

Where scaling is a potential issue within the quill and / or the receiving water pipe the designer shall consider the need for:

- duplicate / standby quills;
- features to simplify the safe removal, cleaning and re-installation of the quill(s);
- features to minimise scaling within the quill and at the quill tip; and
- in-situ cleaning to avoid the need for retractable quills.

Intermittent Flow Considerations

In many systems, both the receiving and dosing flow will be intermittent. The installation may need to consider means such as non-return valves and pressure sustaining valves (or automatic isolation valve) to reduce or eliminate inter-fluid mixing (e.g. siphoning, diffusion) during non-dosing periods, both from the dosing line into the receiving water and from the receiving water into the dosing line.

Materials

Quills must be chemically compatible and resistant to both the dosing and receiving water fluids, to cope with any reactions / change in fluid properties that occur at the dosing interface. The materials requirements for quills are similar to spears (refer to section 3.5.4.5.1), although in small diameter pipelines, the quill may be sufficiently short that a plastic quill (e.g. PVC) is suitable.

Access, maintenance and safety

The designer shall give due consideration to safety and maintenance including:

- ease of access (which impacts safety risk and time to perform maintenance);
- chemical barrier protection (refer to DS79-03);
- access/ adequate withdrawal length;
- for larger pipes, installation in the horizontal plane for ease of withdrawal;
- avoiding the risk of minor fluid leakage onto the pipeline;
- safety shower/ eyewash;
- isolation of both the dosing line and the quill, and provision for flushing;

- anti-siphon / back-pressure / check valves - these should be installed as close to the quill as possible. Spring-loaded check valves are preferred;
- flexible hoses and unions (for quick and easy disassembly) versus rigid pipework; and
- retractable quills shall only be considered where the required force ("ejection force") to insert or retract the quill is less than 120 Newtons.

4.3.4 Spears

4.3.4.1 Mixing Performance

Various texts such as *White* Ref 2, *Kawamura* Ref 3 et al discuss a methodology for calculation of mixing energy "G" for counter-flow diffusers including the effects of flow disturbance by the spear, jet energy and counter-current benefits. However, the mixing efficiency (how well distributed) and the mixing distance are not defined.

Assuming all mixing energy is effectively consumed within about two seconds, spear flows of 0.5-1% of the receiving water and counter-current spear orifice velocities of 6-9 m/s result in G values of over 500 s^{-1}.

The mixing distribution pattern from cross-flow spears can reasonably be predicted by varying both the orifice size and distribution and using methods outlined by *Chao & Stone* Ref 8 and others to predict the orifice jet profile as well as mixing energy.

The spear orifice must be sized to create sufficient hydraulic back pressure so that the injection pressure distributes the chemical correctly across all orifices. Orifices should be designed for velocities in the range of 6 m/s to 9 m/s and to generate head losses at least 10 times that of the head loss across the length of the spear pipe from first to last orifice. The chemical solution velocity (velocity head) within the spear pipe entry should be below 1.5 m/s as higher velocity tends to result in greater discharge rates from the holes towards the tip of the spear.

4.3.4.2 Installation and Design

Mixing is most rapid (i.e. in the shortest distance) where the dosing spear has orifices spaced across the whole pipe diameter. However, practical constraints may require use of shorter spears. These constraints include the hydraulic forces (and vortex induced vibration) on the spear which are more significant with long cantilevered spears; hence, the standard design has full diameter dosing spears only for pipelines sized DN700 and smaller, but half-diameter spears for pipelines sized DN800 and larger.

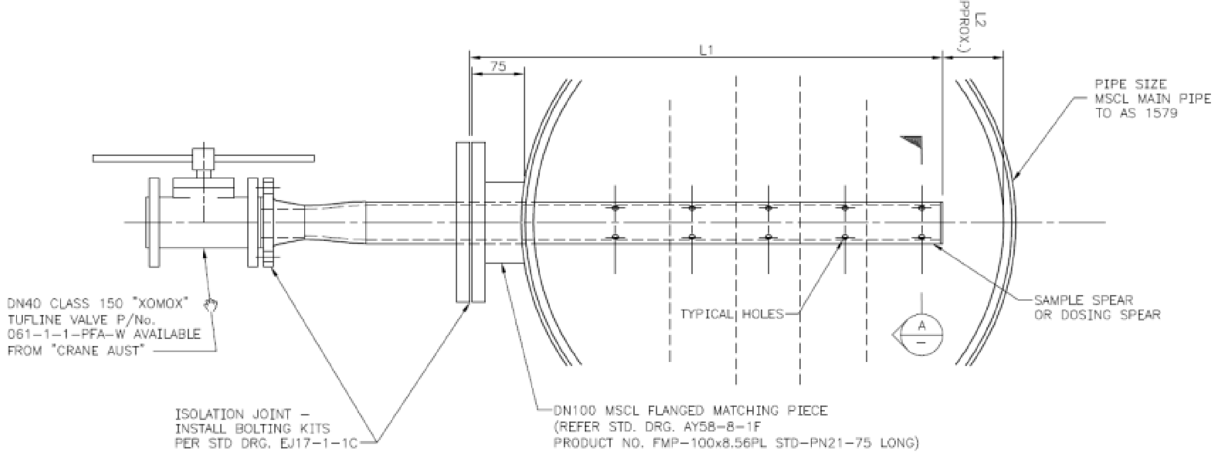


Figure 4-18 – Ideal dosing spear hole configuration - equal area segments across whole pipe diameter

Spears have many of the same design considerations as quills but are more complex due to their longer length and the multiple orifice perforations. Spears have closed ends, though drilling orifices in the end of the spear reduces mixing length (refer to discussion following Table 4-4 in section 4.3.2.1). Spears should be avoided if possible in the following situations:

- counter-current configuration in non-screened raw surface waters (orifice blockage risk);
- dosing of slurries (buildup / non self-cleansing); and
- dosing of potentially scaling chemicals.

4.3.5 Static Mixers

4.3.5.1 Mixing Performance

Static mixers achieve mixing using fixed vanes internal to the pipe that also cause a definable pressure drop. The attractiveness of static mixers is lower energy consumption and reduced maintenance requirements than mechanical mixers because they have no moving parts. Static mixers are highly engineered devices.

Static in-line mixers are continuous radial mixing devices, characterised by an effective degree of plug flow. Since they have short residence times and little back-mixing, proper dosing of the feed components with no short-term flow rate fluctuations is necessary for good performance.

A high degree of homogeneity can be achieved in a very short length of pipe however the receiving water pipeline must have the available head to be used by the static mixer to create the pressure drop necessary for mixing.

Of note is that the majority of static mixer manufacturers have verified the performance of smaller mixers by physical testing (e.g. dye tests), and the larger mixers by CFD modeling, and thus performance is predictable at the reported CoV measurement point. Data on continued mixing beyond the CoV measurement point may be limited.

There is significant difference in specified head loss characteristics between different static mixer makes and models, as well as differences in the location where the CoV is measured.

Long-pattern, vaned mixers in general appear to have better mixing performance than short-pattern mixers i.e. lower pressure drop and shorter distance to achieve equivalent mixing however:

- the actual mixing distance (and thus time for mixing) from where the injected chemical is located may be considerably longer due to the length of the mixers;
- they usually rely on a specific injected flow rate / velocity, and/or distance upstream of the first mixer element (via spear) to achieve the mixing uniformity quoted in the literature; and
- because long-pattern, vaned mixers rely on friction and associated turbulent diffusion, which reduce proportional to the receiving water velocity, mixing performance (CoV achieved or distance required) may be significantly different at lower than design flows.

Broadly speaking, long-pattern static mixer bodies may be up to five pipe diameters in total length, including the built-in empty pipe sections, and can achieve CoV below 0.05 for moderate amounts of additive mixing capacity.

Because CoV may also be dependent on the characteristic of the injected fluid flow for a specific design condition, some static mixers may be suited only for use in water mains with constant flow rates.

Static mixers have traditionally been used for coagulant mixing. For optimum dosing of inorganic chemicals, good mixing should ideally be achieved within 2-3 seconds from the point of chemical injection. Thus, flow variability, mixing time and mixing distance are highly important inputs to static mixer selection.

4.3.5.2 Installation and Design

When evaluating static mixers as a mixing option, the very significant differences between mixers should be understood before selecting static mixers as a solution. The important aspects to establish include:

- the mixing length to achieve the required CoV;
- from what start point does the manufacturer define the mixing length;
- are more than one fluid injection points required to achieve the CoV specified;
- are there any specific injection flow / velocity ratios or a specific injection port diameter required to achieve the CoV specified;
- how does mixing efficiency vary with main water flow;
- how does mixing efficiency vary with injected chemical flow;
- what is the pressure loss, and what is its relationship to main water flow;
- what are the quill / spear requirements (retractable, duplicate etc.);
- are the mixer elements removable (and is there a need for them to be); and
- how will the mixer CoV and head loss performance be verified or guaranteed by the supplier.

Size

Static mixers are available from a variety of suppliers in many sizes that may be considered for Water Corporation projects.

Receiving Water Pressure

This will impact on the body design and any required quills and or spears.

Scaling Considerations

If scaling is a potential issue on the static mixer elements, then consideration must be given to the maintenance requirements including:

- need for a bypass, isolation valves or spool piece;
- dismantling joints, lifting arrangements;
- need for removable elements; and
- pressure monitoring.

Intermittent Flow Considerations

Intermittent flow considerations for static mixers are the same as for quills and spears.

Materials

The materials of the mixing elements need to be compatible with the chemicals to be dosed at the maximum concentration likely to encounter the mixing elements.

Overall Length and Installation Requirements

If installed underground, the space provided within the access chamber needs to allow for:

- the static mixer(s);
- chemical dosing quill or spear;
- chemical barrier protection covers;
- dismantling joints; and

- access for installation, removal, operation and maintenance activities.

Access, maintenance and safety

The designer shall give due consideration to safety and maintenance requirements, related to:

- confined spaces and Regulations; and
- servicing of chemical dose points.

4.3.6 Tee Mixers

4.3.6.1 Mixer Performance

Tee mixers do not provide significant reduction in mixing distance, and so should not be considered except where other reasons take priority such as management of scaling.

Considerations include:

- mixing performance is highly sensitive to the jet being off centre a short distance, which is unlikely to be practical where there is variation in ambient flow rate;
- when aligned with the centerline, tee jets have slightly better mixing performance than central injection; and
- multiple tee jet injections do not provide a significant decrease in mixing distance.

If a turbulent jet (of dosed fluid) with enough momentum is injected across the ambient flow, then this can create rapid initial mixing; however, a momentum ratio greater than 0.013 can result in over-penetration such that the jet impacts the opposite wall of the pipe. For the case of a single jet, the most rapid initial mixing occurs when the jet distributes the dosed fluid symmetrically about the pipe centerline, as illustrated in Figure 4-19.

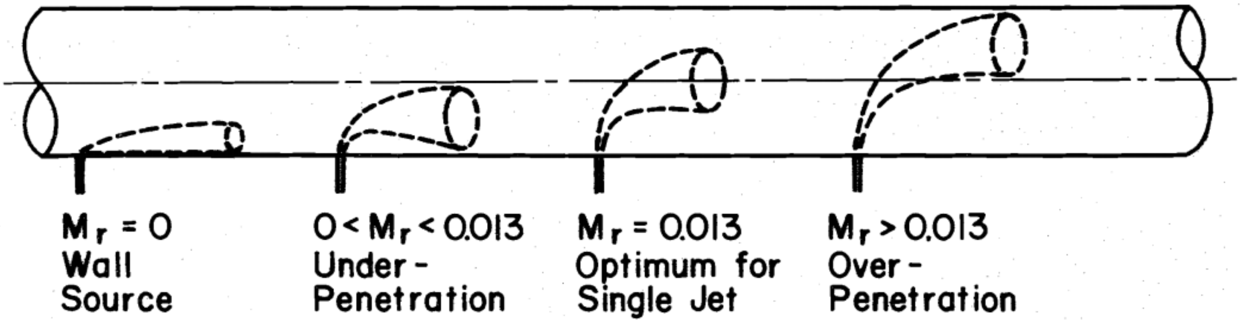


Figure 4-19 – Penetration of jet shown with various momentum ratios

If injecting the jet at an angle against the ambient flow (i.e. > 90°), more rapid initial mixing is achieved because the jet is vigorously sheared and broken up by the ambient flow. Note that as the angle increases towards 180° there will be a greater power requirement to drive a jet into the ambient flow. Data presented by Stephenson and Holley Ref 7 indicates there is an optimum ratio of jet momentum ($M_j = v_j$ x d_j) to the momentum in the receiving water pipe ($M_p = v_p$ x d_p) that gives the shortest mixing distance for low volume Tee mixers. The optimum ratio varies according to the angle of the jet relative to the direction of the receiving water flow.

Table 4-7 summarises the findings to obtain a CoV of 0.03, as compared to central and wall injection. Note that the counter-current jet (150°) had 35% shorter mixing length than a 90° jet, but this would use more energy because it required six times the amount of momentum.

Table 4-7 – Comparison of Mixing Distance for Types of Tee Mixers

Type of Tee Mixer	CoV Achieved	Momentum Ratio (Mj/Mp)	Dimensionless Mixing Distance (Z)
Wall Injection	0.03	-	~0.77
Central Injection	0.03	-	0.3
Single Tee Jet 90°	0.03	0.013	0.28
Single Tee Jet 120 °	0.03	0.019	0.26
Single Tee Jet 135 °	0.03	0.045	0.23
Single Tee Jet 150 °	0.03	0.080	0.18

These findings indicate that use of low momentum side-tee injection, while significantly better than wall injection, has little benefits over central injection i.e. from a simple quill. Injection in a slightly counter-current manner decreases mixing distance but requires a higher momentum / energy jet.

Application of single low volume / low momentum ratio Tee jets in asymmetric injection arrangements may be acceptable as a means of avoiding use of injection quills in the main water flow. However, any assumption for better mixing than a simple wall injection will need to be justified by the designer.

4.3.6.2 Installation and Design

The general considerations for the design of side-tee mixers are similar to that for quills, i.e. consideration must be given to:

- receiving water pressure;
- receiving water velocity;
- location of quill injection tip;
- tip design;
- scaling;
- intermittent flow;
- materials, and
- access, maintenance, and safety.

If chemical is injected into a solution side stream immediately before injection as shown in Figure 4-20 – Side-Stream Injection, this may offer advantages in being able to isolate and de-pressurise the side stream and thus avoiding the need to de-pressurise the main or require retractable quills.

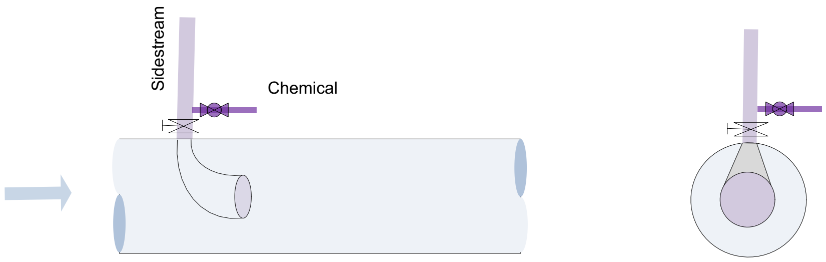


Figure 4-20 – Side-Stream Injection

4.3.7 In-Pipe Jet Mixers

4.3.7.1 Mixer Performance

The use of relatively high volumes of water to achieve effective coagulation flash mixing is well documented.$^{\text{Refs } 3,5,6,8}$

Impingement jet mixers use about 3% of the volume of the receiving water flow injected against a conical or sometimes grooved deflection plate which deflects the water radially within the receiving water. Jet mixers are less attractive when dealing with either very small or very large volumetric flows. The injected water velocity is typically 7-9 m/s, and with careful design, can have a high co-efficient of discharge (>0.9), and with a head requirement of 3-5 m through the nozzle.

Commercial full jet spray nozzles can also be used, though these typically require 4-5% water and a driving head of 5-7 m upstream of the nozzle. Mixing is achieved in 1-3 seconds. Due to the symmetrical arrangement of the design, mixing energy is efficiently distributed throughout the receiving water.

4.3.7.2 Installation and Design

Due to the high volumes of water required for mixing and relatively low pressures, mixing water is often supplied by a dedicated pump rather than from higher pressure service water, particularly for larger water treatment installations. If pumps are used as a source of water, the duty should initially be selected assuming a minimum 8 to 10 m head for impingement mixers, and 10 to 12 m head for nozzle style mixers. This head allows for pump fittings and other losses.

Performance

The designer must assess the applicability of flash mix design to the mixing application. Reduction of injected water volumes and velocities, and application in systems where pipeline flow is high, may change considerably the manner in which chemical is distributed within the water columns to that of flash mixing i.e. the time and or distance within which full mixing will occur. Key issues to be addressed hydraulically are:

- the mixing volume in which mixing is to be achieved;
- the water jet trajectory within the receiving water; and
- the time / volume required for complete mixing.

Scaling Considerations

If scaling is a potential issue then consideration must be given to the maintenance requirements including:

- the need for a bypass, isolation valves or spool piece;
- access to the dosing point; and
- design of the injection point to minimise or eliminate scaling potential.

Intermittent Flow Considerations

Intermittent flow considerations for in-pipe jet mixers are the same as for quills and spears.

Materials

The mixing elements need to be compatible with the chemicals to be dosed at the maximum concentration likely to be contacted with the mixers. Stainless Steel Type 316 is a minimum for metals. Titanium may be needed for concentrated ferric or hypochlorite solutions.

Overall Length and Installation Requirements

If installed underground, the space needed within an access chamber needs to allow for:

- a large, purpose-built flange through which the mix water and chemical water pipework may pass;
- a static mixer if required; and
- access to all of these items.

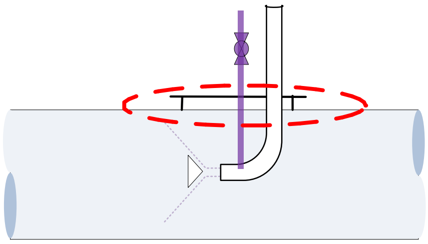


Figure 4-21 – Space Requirement for Flanged Dosing Entry

Access, maintenance and safety

The designer shall give due consideration to safety and maintenance requirements, related to:

- confined spaces and the relevant Regulations;
- chemical barrier protection (refer to DS79-03); and
- maintenance of the chemical dose points.

4.3.8 Miscellaneous Mixing Devices / Opportunities

4.3.8.1 In-Line Mechanical Blenders

In-line mechanical blenders are not preferred.

4.3.8.2 Pump Mixing

The presence of a pump station may provide opportunity for rapid mixing because some types of pumps (and the bends in pipe manifolds) may generate significant turbulence. If chemicals are dosed to the suction side of pumps to achieve mixing, assumptions related to the CoV achieved downstream of pumps will need validation by the designer. Chemical dosing should be sufficiently far upstream of the pump station to avoid corrosion of the pumps from exposure to local high concentrations due to incompletely mixed chemicals, or alternatively pumps may be specified for chemical service.

4.3.8.3 Pipe Junction Mixing

Similarly, assumptions related to mixing efficiency downstream of two joining pipes (a pipe junction) is highly dependent on the flow ratios and the geometry, and assumptions related to the CoV achieved by the arrangement will need validation by the designer.

5 BIBLIOGRAPHY & REFERENCES

Sources of information related to conduit mixing as well as chemicals, their properties, design issues and installation considerations include:

- various texts including:
  (1) Handbook of Industrial Mixing, Science and Practice, E L Paul, V A Atienmo-Obeng, S M Kresta
  (2) Handbook of Chlorination and Alternative Disinfectants, George Clifford White
  (3) Integrated Design of Water Treatment Facilities, S Kawamura
  (4) Perry's Chemical Engineers Handbook, Perry
  (5) Water Treatment Plant Design, AWWA / ASCE
  (6) Water Treatment Principles and Design, MWH
- published papers including:
  (7) Jet injection for Optimum mixing in Pipe Flow, WRC Research Report No 144: S.D. Fitzgerald and E.R. Holley (1979)
  (8) Initial mixing by Jet injection Blending, J-L. Chao and B.G. Stone, Journal AWWA, October 1979.
  (9) The design of in-line injection blenders, Research & Technology, Oktay Güven and Larry Benfield, Journal AWWA, July 1983.
  (10) Mixing in Pipelines with Side and Opposed Tees, Zughbi H D, Khokhar Z H, and Sharma R N, Ind. Eng. Chem. Res. 2003, 42, 5333–5344, July 2003.
- Safety Data Sheets (SDS) - noting that SDS information is often limited and may only contain relevant physical properties at a single temperature/ pressure condition.
- Chemical Bulk Installation Guidelines and supplier's chemical technical handbooks. (While these tend to be orientated towards bulk storage, some also provide detailed information on various design aspects as well as chemical properties, reactions, and recommended piping, valves and jointing types and materials.)
- chemical suppliers - for specific information on fluid properties over a range of temperature and pressure conditions and for specialty chemicals.
- equipment vendors - for specific information on installation, materials, and mixer performance.

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