MANAGING THE SAFETY CHALLENGES IN COMMISSIONING AND OPERATION OF LARGE SCALE RO SEAWATER DESALINATION PLANTS

Authors: ***Sean Anthony McCagh***, *Scott Murphy, Tom Pankratz, Steve Pickering, Mark Thompson.*

Presenter: **Sean McCagh**
Director – McCagh O'Neill Pty Ltd – Australia
Sean.McCagh@moconsulting.com.au

Abstract

Seawater desalination by reverse osmosis (RO) presents a unique and arguably new set of challenges to the water supply industry in its high pressure of operation, corrosive fluid, and highly modularized technology. Like any process industry with similar risk profiles, continued vigilance and collective effort as an industry is required to minimize failures and the potential for harm to personnel and assets.

Significant high consequence failures have occurred during commissioning and operation of seawater RO plants. High level accounts of these failures have been previously published [1]. This paper provides an account of the response to some of these known failures at Gold Coast Desalination Plant (GCDP).

In light of the risks and emerging information, the owners and operators of the GCDP recently undertook a significant review of the hazards and operations, with the objective to reduce the risk so far as is reasonably practicable (SFAIRP) and to give stakeholders comfort that the plant is safe. The review included a failure mode analysis for high pressure components, risk assessment, implementation of design changes, operational procedures, changes to inspection and maintenance procedures, training, and record keeping.

As part of that review, it was identified that the 'tolerable risk' approach to risk management did not deal adequately with low likelihood, high consequence risks in the context of current Australian legislation which requires risk to be eliminated, or if not able to be eliminated, reduced SFAIRP. Where under a tolerable risk approach, the extremely low likelihood of a high consequence failure would often result in no further action being required, the SFAIRP approach requires that all reasonably practicable precautions are in place regardless of whether the total risk is deemed to be at a 'tolerable' level.

This required that the best available advice on the suite of risks and possible precautions was developed, taking into account experience of similar operations. Assuming the same logic applies to all desalination facilities, the proactive sharing of information with the wider industry should continue as an ongoing priority for owners and operators.

One of the many control measures implemented at the GCDP are exclusion zones to minimize exposure of personnel to plant hazards where deemed reasonably practicable.

I. INTRODUCTION

Significant, high consequence failures resulting in the uncontrolled release of energy have occurred during commissioning and operation of reverse osmosis (RO) seawater desalination plants. The unique combination of modular technology, corrosive media and high pressure; present a challenge for water supply authorities and operators. This is particularly the case for bulk supply plants such as the Gold Coast Desalination Plant (GCDP), designed and constructed to produce 125 million litres per day (MLD) of very high quality potable water to provide safe, reliable, long term water security to South East Queensland (SEQ), Australia.

In light of the known safety risks and emerging new information on possible failure modes, owners Seqwater and alliance partners Veolia Water Australia Pty Ltd (Veolia), and John Holland Pty Ltd recently undertook a significant review of the hazards and operations with the objective of reducing risks SFAIRP and to give stakeholders comfort that the plant is safe. This paper outlines the high pressure incident history of seawater desalination, the issues that emerged at GCDP in 2010 leading to the review of hazards, and some interesting outcomes that can be applied to the industry.

II. DESALINATION IS DIFFERENT – UNIQUE (IF NOT NEW) CHALLENGES

2.1 A Unique Technology on a Large Scale

Large scale RO desalination plants represent a unique process given the combination of high pressure, a highly modular process, the use of fiber reinforced plastic (FRP) pressure vessels, high pressure grooved style couplings and a corrosive media.

In other industries, technology typically grows in scale with the process demand, resulting in specification of a larger process unit rather than an ever increasing array of standard size units. Reverse osmosis units are an exception to that rule being for most practical purposes, limited to the 8” diameter vessel, with a potable water production capacity of just $3m^3$/hour per vessel in seawater desalination. Use of the technology at a large scale for city water supplies requires high quantities of these vessels which in turn results in a very high monitoring demand due to the inherent concentration of components and joints, particularly given the criticality of monitoring leaks to the integrity of the plant. The GCDP, as an example, consists of around 2,200 RO pressure vessels, with up to four inlet/outlet joints per vessel.

In high pressure process industries such as oil and gas and power generation, FRP pressure vessels and grooved style couplings are not typically utilised, with a preference for steel, with welded and flanged joints.

2.2 Lack of Regulation

The retention of pressure energy is the key issue. The pressures and temperatures in seawater desalination, and the size of ‘storage’ volume in individual vessels are not significant enough to warrant regulation under existing pressure standards (in Australia), particularly given the relatively benign nature of the contents compared with flammable liquids and compressible gases.

However, it must be noted that the unique risk factors associated with high pressures in bulk scale RO seawater desalination being the corrosivity of fluid media and high concentration of FRP vessels and grooved coupling style joints, could not possibly have been contemplated at the time of development of Australian and international standards applying to pressure equipment regulation. There is the potential that future assessments may result in the introduction of relevant regulation. Naturally, the safety performance of the industry will play a significant role in whether such regulation occurs.

Taking these factors into account, bulk scale RO seawater desalination then presents a unique monitoring and management challenge.

2.3 A Paradigm Shift for the Water Industry

In addition to the fact that the RO desalination process is unique as an industry, Pankratz [1] described the chasm between conventional water supply and desalination in a number of areas. Operators from conventional water treatment backgrounds are being exposed to a risk set they have not faced before when required to operate seawater reverse osmosis plants.

Conventional water treatment, typically comprising filtration of surface water, operates at pressures an order of magnitude lower than that required for reverse osmosis, with a relatively non-corrosive fluid, and typically between one and twenty units of each process.

Treatment plant operators that move from conventional to desalinated water treatment then have a range of unfamiliar equipment and issues to come to terms with, such as:

- the energy potential of the high pressure process, and associated criticality of monitoring, maintenance and operational practices
- the requirement for those practices to apply across thousands of individual items of equipment
- FRP RO pressure vessels and grooved couplings with specialized maintenance requirements and failure modes
- exotic stainless steels with complex requirements for quality control in refurbishment and replacement
- high potential for corrosion, including crevice corrosion in dead legs of piping and the need for flushing of saline fluids from metallic surfaces during offline periods.

The fact that these issues are often new to operations and maintenance staff, increases the challenge for the industry in managing the risk set. This then increases the importance of clear and effective procedures, training and quality assurance programs.

III. DESALINATION FAILURE HISTORY, AND EMERGING INFORMATION

3.1 Incident History

To date, sharing of information regarding failures has occurred, particularly within organisations, but has not been systematic across the industry. The topic of desalination safety has not been strongly featured in literature to date, with a couple of notable exceptions.

Pankratz [1] documented an anecdotal history of desalination plant failures. Over the last few decades there have been a number of Fibre Reinforced Plastic (FRP) pressure vessel failures, the most dramatic of these resulting in components being projected through adjacent building walls. While it is pointed out that many improvements in design and process control have been implemented since major failures in the late 1970's, the problem remains, evidenced by failures in the Middle East and the Caribbean in the early part of this decade.

Destructive grooved coupling failures have also occurred. In the mid 1980's an experienced industry member was killed when a coupling failed, reportedly due to corrosion. The industry was more recently reminded of the potential for harm, when an incorrectly assembled fitting lead to a fatality during commissioning in 2009. Flange and compression fitting joint failures relating to assembly and corrosion in operation are also known to have occurred.

Other issues of concern in bulk desalination plant safety include the presence of turbulent water bodies in intake and outfall structures, less industry specific issues such as confined space entry and working at heights, and the problem of new suppliers entering the industry without a detailed understanding of the failure potential of the process.

3.2 Emerging Quality Concerns

Eisberg [2] provided perspective on the risk for the industry if established standards are not followed by such suppliers (in relation to FRP vessels) and in the same paper warned of the importance of operational vigilance when preventing and repairing FRP vessel leaks.

Eisberg argued that the American Society of Mechanical Engineers Boiler and Pressure Vessel Code Section X (ASME X) provided the industry's best safeguard against RO pressure vessel failure and that changes in the market had resulted in a relaxing in specifications. In particular, vessels were being specified as being require to comply with ASME X, but without the assurance of a third party certification and stamp.

For those organisations managing pressure vessels without the assurance of an ASME X stamp, Eisberg proposed vigilant monitoring for leaks and other signs of flaws in condition, noting that the presence of external coatings often compromised the ability to detect flaws prior to a leakage event.

While ASME X has traditionally formed the basis for design of pressure vessels, there is no industry wide standard for operation and maintenance of these vessels.

3.3 Commissioning and Early Operational Experience at GCDP

3.3.1 Commissioning Practices – Pankratz's survey confirmed the industry's understanding that start-up is the most hazardous period in the life of a desalination facility. Risks during commissioning are increased because of the unproven nature of much of the high pressure system and further exacerbated by the number of construction personnel, that at times, could be working within the vicinity of high pressure equipment being started up. Experienced RO desalination commissioning staff at GCDP adopted a one hour exclusion zone policy for equipment being pressurized for the first time or re-pressurized after any mechanical intervention. During this exclusion period only commissioning personnel were permitted inside the RO building, thereby significantly reducing the likelihood of any safety impact of high pressures during start-up.

The policy continued into the operations phase of the project any time maintenance of high pressure components occurred, effectively requiring re-commissioning of plant. The policy was successful in that the start-up failures that did occur had no impact on personnel. However, it is noted that not all commissioning/ re-commissioning related failures occurred during the one hour window.

3.3.2 High Pressure Incidents – GCDP experienced a limited number of high pressure failures during commissioning and early operation including flanged and bolted joint and compression fitting failures. Each event was investigated thoroughly to determine and address the root cause.

Ball valve bolts failed due to the use of unspecified material resulting in a high pressure jet causing damage to building structure. 3rd party quality checks instead of reliance on the supplied material conforming to specifications could have prevented the failure.

High pressure release from a flanged joint occurred due to flange misalignment, and in another case due to a breakdown of the permit to work system. In each case, the failures resulted in significant damage to surrounding structures, illustrating the potentially catastrophic consequence had personnel been in the vicinity at the time. These events served as a reminder that even when highly qualified personnel carry out works, vigilance is still required via clear procedures, regular training, and third party checks to ensure required standards are being met.

Figure 1: Damage to building due to high pressure flange failure

3.3.3 Threaded Joint Corrosion – During early operation (August 2011) widespread threaded joint corrosion was discovered across the RO process areas. A small leak on a drain valve was the first indication. Further investigation found a number of threaded connections with corrosion, primarily manifold drains and in pump casing drains, but also in various other applications.

As a precaution while the issue was being investigated, a policy of total exclusion of personnel from the RO building during high pressure operation was implemented.

Figure 2: Example of corrosion of threaded fittings encountered in RO seawater desalination service

3.3.4 Pressure Vessel Leaks – Around the same time that the threaded joint corrosion was discovered, a significant number of pressure vessel leaks were identified. Given Eisberg's advice, supported by the vessel manufacturers, that leaks were not to be tolerated, there was a concern that the leaks may be indicative of a causative underlying flaw, or that the leak itself may be causing damage to the vessel. While GCDP RO vessels had been specified as required to comply with the ASME X code, they were not required to be 'code stamped'. This, in light of Eisberg's description of quality risks in the industry being exacerbated by the lack of code stamps, created doubt amongst some GCDP team members as to whether the code requirements had actually been met, and whether the observed leaks were indicative of an underlying design or construction flaw.

IV. REVIEW AT GCDP AND OUTCOMES

In light of the risks and emerging information at that time, the owners and operators of GCDP undertook a significant review of operations to reduce risks SFAIRP and to give stakeholders comfort that the plant is safe.

4.1 Method – Failure Mode Analysis

The review comprised of a failure mode analysis for high pressure components in order that methods of mitigation could be implemented. In addition a risk management consultant (R2A) was engaged to provide more surety of a robust analysis process and outcome. This initiative was considered appropriate given the potential magnitude of consequence that could have resulted from a high pressure failure, and considering the complexity around the issue.

4.2 Tolerable Risk Level versus Reasonably Practicable Precautions

R2A provided advice that the ‘tolerable risk’ approach to risk management inherent in the Australian and international standards did not deal adequately with low likelihood, high consequence risks in the context of current Australian law that requires all reasonably practicable precautions to be in place.

Under conventional risk management standards, an organization could accept risks that were quantified as a lesser total risk value than a benchmark ‘tolerable’ value. This could result in high consequence risks being accepted due to an assumption of a low frequency of occurrence, which lead to an overall low value of calculated risk. By this method, even very effective, simple and low cost precautions are not required to be implemented because the level of tolerable risk has already been achieved.

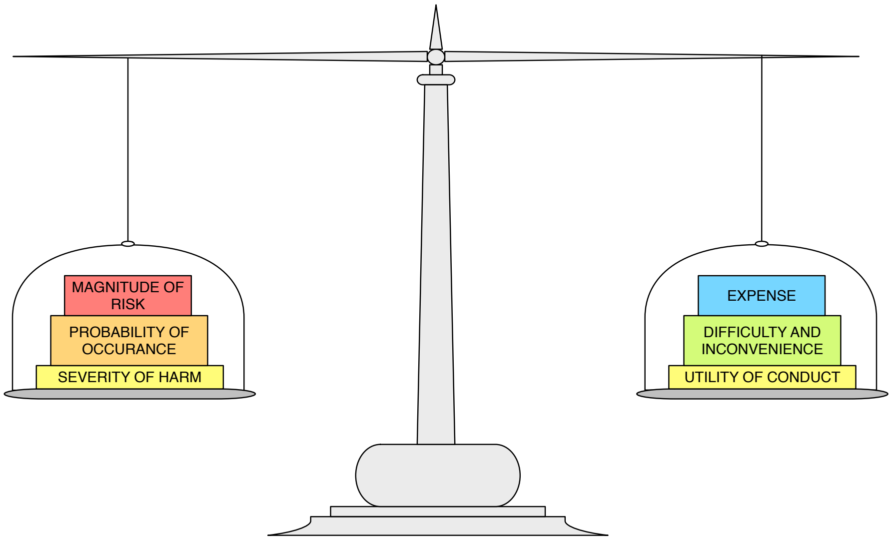
Under recently updated Australian safety laws including Queensland’s Work Health and Safety Act 2011 [3], ‘what is reasonably practicable in ensuring health and safety’ is defined as that which is:

“reasonably able to be done…taking into account and weighing up all relevant matters including … likelihood… degree of harm…what the person..ought reasonably to know about…ways of eliminating or minimizing the risk…availability and suitability of ways to eliminate the risk…the cost associated with available ways of minimizing the risk, including whether the cost is grossly disproportionate to the risk”.

The last point and the exercise of assessing whether cost is grossly disproportionate to the risk is represented and can be neatly visualised by the scales of figure 3.

Critically, the obligation then is to understand the available methods of prevention, and to implement these except where the scales are clearly tipped to the right, such that cost cannot be justified against the risk, regardless of any quantification of total risk as low.

Figure 3: Risk balance diagram (courtesy R2A)



By R2A's interpretation, a due diligence approach requires thorough investigation of high consequence hazards and possible precautions using best available knowledge and expertise. This means that the application of industry wide knowledge to the problem is a fundamental requirement.

4.2 Identification of Possible Precautions

In determining possible precautions, failure modes and potential barriers to failures were reviewed. In accordance with the requirement for the best available advice, key members of operations and maintenance teams were consulted through the process and knowledge gained from visits and discussions with industry counterparts were drawn on. A threat barrier diagram was constructed to determine the most effective barriers to failure based on broad probabilities of event and possible outcomes.

Some of the key failure modes/causes identified were FRP vessel delamination or retaining component corrosion, crevice corrosion of threaded joints, incorrect material application and inadequate training leading to incorrect installation/maintenance.

Serious consideration was given to the problem of exclusion of personnel from operating areas, which on the one hand effectively removes risk, but on the other hand, tends to increase the hazard level due to reduced effectiveness in identifying and correcting issues before they develop into a major hazard.

4.3 Outcomes

The outcomes of the work were many. GCDP has implemented on going exclusion zones to minimize exposure of personnel to plant hazards. This exclusion zone still allows for safety and production critical maintenance to occur. While work has been undertaken to best ensure safety of the plant, access will continue to be restricted to minimize the low probability, high consequence risk of personnel being injured as a result of a high pressure failure. The clearest example of this then is attention to pressure vessel leaks where intervention can mean the difference between trouble free operation and catastrophic delamination failure.

Threaded joints have now been designed out of high pressure areas at GCDP, replaced by flanged, compression and Victaulic style couplings. While the likelihood of a threaded joint catastrophically failing was assessed as low due to the nature of the joint, it was determined that due to the sheer quantity of these joints, the imposition in monitoring and management of the risk was unacceptable to the operation.

Changes to inspection and maintenance procedures relating to all identified failure modes were made to further mitigate failure risk. Additional schedules have been put in place to ensure that training in safety critical areas is kept up to date and to carry out quality checks on newly supplied equipment independently of the supplier.

In order to address concerns relating to pressure vessel leakage and Eisberg's postulation that the lack of an ASME X code stamp on the GCDP vessels represented significant quality/ integrity risk, a detailed inspection of installed pressure vessels was carried out along with a design check. Advice was given that the design of the vessels is acceptable for the application, and there was no evidence of substantial damage to any of the vessels, but again, that ongoing monitoring for leaks or other defects was critical.

Regarding the need to engage with the industry regarding safety, GCDP staff supported by the Centre of Excellence in Desalination Australia championed a convening of Australian desalination plant operations personnel, in order to foster improved information sharing. The event allowed the informal sharing of safety and incident information, and served to strengthen networks, increasing the opportunity for efficient communication of the risks presented in RO desalination plants.

Since the implementation of these improvements, high pressure failures have reduced from 8 failures between 2007 and 2012 to no failures since the implementation of the work.

V. CONCLUSIONS OR RESULTS

Failures have occurred in seawater desalination plants and vigilance is required to ensure potential for failures and associated harm is minimal. Removing people from the area of risk is a valid strategy, critical during commissioning and re-commissioning, but not practicable as a complete solution given the need for manual intervention for safety and production critical activities. Each water authority must make it's own determination of under what conditions exposure to high pressure risk is justifiable.

Based on GCDP experience, the use of threaded joints in high pressure seawater applications should be avoided due to the crevice corrosion risk, with a corresponding hazard and a consequent high maintenance and monitoring load.

Investment in quality inspections, checks and controls is particularly important in the desalination industry where components are sourced globally using exotic materials.

While seawater RO desalination safety is clearly a problem of risk management, the high pressure failure issue does not fit well with conventional risk management in that the concept of tolerable risk levels does not adequately deal with low probability/high consequence high pressure failures. All reasonably practicable precautions need to be in place, taking into account the best available knowledge, which requires sharing of incident information across the industry. Organisations such as the International Desalination Association internationally and the National Centre of Excellence in Desalination Australia and Australian Water Association in Australia are critical to fostering the relationships that will assist in sharing learnings, as well as formal presentation of experience through technical programs. An industry wide system of safety alert would also serve desalination operators, maintainers and designers well. Ongoing assessment of status as to what is reasonably practicable is required to reflect change in circumstances, new information reflecting changes in risk level and costs of the implementation of risk mitigations and barriers.

High pressure equipment deserves respect. Bulk supply scale RO desalination is relatively new and it's unique risk profile, may take some time to be fully considered by standards committees. While at least in Australia, a single RO vessel is technically not of significant enough hazard level to be covered by regulation, rigorous processes of condition monitoring and inspection should still be implemented. An opening exists for operators to work together to develop a best practice standard for management of high pressure risks for the benefit of the industry as a whole.

Preventable harm may occur if communication regarding hazards and their root causes is ineffective.

VI. REFERENCES

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