Hydrated lime handling systems for thermal enhanced oil recovery: Guideline development report

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1.0 Executive summary

High calcium hydrated lime ($Ca(OH)_2$) is commonly used in water treatment to neutralize acidic solutions and to reduce water hardness and associated alkalinity. Benefits of softening water include reducing dissolved minerals and scale-forming tendencies, removing heavy metals, removing certain organic compounds and total organic carbon, and reducing silica. In thermal enhanced oil recovery systems lime is used in conjunction with magnesium oxide (MgO) to increase the reactor pH to facilitate silica removal, improve sludge consistency, and to reduce hardness.

As a portion of the water treatment process in the oil sands, lime is used to neutralize process water (produced water and makeup water), to meet requirements for boiler feed water quality. The majority of thermal enhanced oil recovery facilities in Alberta currently have a lime handling system as a portion of their water treatment process. The operation and maintenance of the diverse lime handling systems pose numerous challenges to facility operators.

Although many challenges are common across the sector, operators have tended to manage them on a plant-by-plant basis with their equipment suppliers and engineering consultants. This approach presented an ideal opportunity to build on the success of the MgO guidelines, by sharing knowledge within the industry on potential mitigation options to address challenges with current systems, and develop lime handling guidelines for system design and operation that will improve the operation of existing and new systems.

MgO and hydrated lime share some physical similarities and the design of the handling systems share many key components. Building on these similarities, together with previous successes investigating MgO handling system guidelines (WaterSMART, 2014), a case emerged for studying the lime handing system. This work focuses on the use of lime for thermal enhanced oil recovery systems in Alberta.

This report provides the background, methodology, and analysis undertaken to develop design and operation and maintenance guidelines for lime handling systems. The document two main purposes:

1) To serve as a resource for operators wishing to develop a greater understanding of the systems, potential system challenges, and how they can be addressed, and
2) To explain how and why the guidelines were developed.

A second report, *Hydrated lime handling systems for thermal enhanced oil recovery: Toolkit* draws on information from this report and can be used as a quick reference for operators developing specifications and standard operating procedures.

Both this report and the second report (*Hydrated lime handling systems for thermal enhanced oil recovery: Toolkit)* can be openly accessed online via www.albertawatersmart.com/featured-projects/best-practice-guidelines.html

This report was developed collaboratively with 10 owner companies, a hydrated lime supplier, a MgO supplier, three lime system equipment supplier and one engineering company. Participating companies shared challenges and lessons learned. All company representatives had an opportunity to attend two workshops and participate in one-on-one interviews. Design information was collected for analysis to compare with information on challenges and successful operations at each facility.

The impact of suppliers and consultants on the design and operation of lime handing systems was observed and discussed throughout this work. Similar conclusions were observed during the MgO guideline development (WaterSMART, 2014). Specifications provided by the facility owner to purchasing, or to the design engineer who in turn provides specifications to purchasing, are the most effective way to ensure important parameters are translated into the hardware. In the absence of owner's specifications, the process for tender and award of equipment and design contract may create a situation where suppliers provide the lowest cost design to win the contract. If lime handling system specifications are not detailed enough, the supply chain process may not provide the most effective or efficient equipment.

Although it is not stated explicitly in the guidelines, a major recommendation is that owners use the proposed guidelines to develop their own specifications for lime handing systems. Many operators indicated they will carry these guidelines forward. Doing so in a formal way will ensure engineering companies are aware of the guidelines and are in a better position to support their implementation.

There were challenges with all major components—correlations between challenges and design and operation of the system could not always be made, or statistical evidence was not strong. Where this was the case, guideline development was supported with anecdotal evidence and documented literature, as indicated in the analysis, and/or benefits and disadvantages of different potential mitigation or design options were provided.

A guideline is a statement used to determine a course of action. A guideline aims to streamline particular processes according to a set routine or sound practice. By definition, following a guideline is never mandatory; guidelines are not binding and are not enforced. The guidelines in this report are for consideration only and should not be considered final design principles.

Design and operation and maintenance guidelines, developed for each key area of interest in the lime handling system, are listed below according to the major process components For each proposed guideline this report contains a corresponding section, featuring the analysis and explanation of the development of the guideline.

Summary of proposed design guidelines

Guideline	Report section
Silo	
D1. Use the silo level measurement device for inventory control only, do not use it as a means for measuring lime dose to the slurry mix tank. Using the silo level measurement device for lime dosing will be less accurate and may cause ongoing system operating and performance issues.	5.2.1
D2. Size the silo vent to match: • the pneumatic flow rate expected from the lime transfer from the truck into the silo, and • air injection into the silo. Lime is transferred pneumatically from trucks at rates ranging from 17m3/min (600 cfm) to 24 m3/min (850 cfm).	5.2.2
D3. Have a filter on the silo vent. For hydrated lime a minimum filter area of 0.09 m2 (1 sq. ft.) of cloth area per 0.085 m3 (3 cu. ft.) of air is recommended. When Jet Pulse dust collectors, involving compressed air bag cleaning, are used, they operate at air to cloth ratios between 3.5:1 and 4.5:1, depending on the fineness of the lime (National Lime Association, 1995).	5.2.2
D4. Include a means of air injection (aeration pads / aeration cone) into the silo to increase the flowability of the lime product and avoid bridging over the silo outlet. Air should not be injected into a silo if there is no rotary valve downstream of the silo. See proposed design guideline number 5 for information regarding mechanical impactors.	5.2.3
D5. Mechanical impactors should not be overused, their use should be optimized in conjunction with the use of an air injection, see proposed guideline number 4. Mechanical impactors can cause vibrations through the system, when they are used care should be taken to understand the risks caused by vibration.	5.2.3
D6. Do not place the process components upstream of the slurry mix tank directly above the tank. This will reduce the travel of water vapor from the tank to these components, preventing lime formation buildup within these process components.	5.2.4
D7. A fully redundant system downstream of the silo will avoid system shutdowns when operational challenges occur throughout the system, and increase the efficiency of the system while it operates. Note that a fully redundant system may be cost and footprint prohibitive.	6.2
D8. Close and seal all open holes in the system where dust has the potential to enter the work environment or buildup on equipment.	6.2
D9. Ensure, if at all possible, that all system components downstream of the silo are located inside a building. If components must be located outside ensure that they are well sealed. This will avoid moisture ingress into the system and help avoid plugging.	6.2
D10. Install a slide gate valve immediately downstream of the storage silo to allow for isolation of the rotary valve and other lime transfer components.	6.2.1
D11. Include a vent on the hopper to prevent plugging and level control challenges in the hopper. The vent should be sized to accommodate the displaced air from the lime powder being fed into the hopper. The vent should have a dust sock.	6.2.2

D12. Use a conventional closed flight screw conveyor for product transfer. A ribbon type screw conveyor should be avoided to prevent bypassing of powder through the conveyor and ingress of water vapor into the conveyor.	6.2.3
D13. Construct the chute from flexible material, such as an absorbent fabric, rubber, or neoprene to prevent accumulation of material on the walls and allow for easier cleanout. A rigid chute may increase vibration in the system and increase wear on the hopper.	6.2.4
D14. If the chute is constructed of a hard material include a y-lateral connection or some other form of cleanout connection.	6.2.4
D15. Caution should be taken if a rotary valve is used as the sole method of lime powder volume control. See Table 6 for a comparison of different lime powder volume control components.	7.2.1
D16. A screw conveyor should not be used as the sole mechanism for lime dosing without another lime transfer component. Screw conveyors are prone to lime flow through if there is no upstream lime control mechanism between the silo and the screw conveyor.	7.2.1
D17. It is recommended that a hopper is included as a component in the powder transfer and lime dosing system. Table 6 offers a comparison between lime dosing strategies.	7.2.1
D18. Slurry mixing modelling should be undertaken to ensure adequate mixing of the slurry in the tank, considering all appropriate variables related to the tank geometry and baffles, and water temperature. The mixer manufacturer can undertake modelling on behalf of the designer. See proposed design guideline 28.	8.2.1
D19. Include a vent system with a vacuum on the slurry mix tank to mitigate dust issues and to control moisture upstream of the slurry mix tank. See guidelines 20 to 25 for tank vent system design. Maintenance is essential to ensure ongoing venting, see operational and maintenance guidelines 12 to 14.	8.2.2
D20. The slurry mix tank vent should be under negative pressure, pulling a slight vacuum on the slurry mix tank. In order to create the vacuum, facilities have had greater success with educator fans, such as a venturi, than with an in-line induction draft fan. Many participants noted that in-line fans tend to get plugged.	8.2.2
D21. Design the slurry mix tank vent as required, to handle the design water temperatures and tank sizing. Consider designing the vent for water temperatures greater than expected design temperatures to ensure the vent can still operate with a change in source water.	8.2.2
D22. The slurry mix tank vent system should include a wet scrubber with baffles. It should operate under negative pressure and vent outside.	8.2.2
D23. The slurry mix tank vent should have baffles. The baffles should be at 45° from the wall and should be staggered (alternating either side).	8.2.2
D24. Locate the slurry mix tank vent as far away as practical from the lime powder inlet. If the vent and the inlet are in close proximity the vent will suck up the powder and plugging will occur more quickly.	8.2.2
D25. If vent plugging is an issue consider including a variable frequency drive (VFD) or a butterfly valve on the vent to allow for manual or remote changes to the vent air intake to prevent plugging (see operational and maintenance guideline 14).	8.2.2

D26. Include four baffles set 90° apart or three baffles set at 120° to promote effective mixing in the slurry mix tank. Baffles should be no higher than the high liquid level.	8.2.3
D27. Baffles should be 1/12 of the tank diameter, perpendicular to the tank wall, and have an off wall space of 1/24 of the tank diameter.	8.2.3
D28. Modeling should be undertaken to determine the optimal agitator impeller design as a function of tank size and shape, the specific gravity of the lime mixture, and the settling rate of the suspended solids.	8.2.4
D29. If modeling cannot be undertaken for the slurry tank agitator design the following rules of thumb should be considered: a. The agitator impeller diameter should be 1/4 to 1/3 of the tank diameter b. Propeller or axial flow turbine agitator blades are often used on smaller tanks and should turn at approximately 350 rpm. Whereas turbine type impellers are often used on larger tanks and should turn at speeds of 100 rpm or less, and c. About 1.5 to 1 hp per 3,785 L (1,000 gal) of tank capacity is required for cylindrical tanks of less than 11,400 L (3,000 gal) capacity and slurry concentrations not exceeding 120 g/L (1 lb/gal). Modeling should be undertaken to determine the optimal agitator impeller design as a function of tank size and shape, the specific gravity of the lime mixture, and the settling rate of the suspended solids.	8.2.4
D30. The slurry agitator impellers should be a minimum of one impeller diameter below the normal liquid level. The agitator speed should be set appropriately to ensure good mixing without splashing.	8.2.4
D31. The slurry agitator should enter the tank from the top, parallel to the tank walls. This may decrease the potential for splashing and solids buildup on the walls, promote effective mixing, and decrease wear on the agitator.	8.2.4
D32. If splashing and solids buildup above the normal liquid level is an issue, add a spray nozzle at the top of the tank to continually wash buildup off walls. This should only be done if the tank has a properly designed venting system.	8.2.4
D33. Use redundant level measurement in the slurry mix tank; having two different level measurement technologies may add value to this redundancy. Facilities have reported success with many different forms of level measurement. The two most common forms of level measurement are ultrasonic and bubble tube. Two facilities noted that radar had not worked for them in the past. There are challenges associated with each level measurement device: • Bubble tube o Significant maintenance is required. o There is a greater potential of scaling compared to other devices. • Radar o The cable type that extends into the tank can become cake with material and require maintenance. o Both cable and cone types can be affected by dust particulate, creating inaccurate	8.2.5

readings. • Ultrasonic o The presence of foam or dust creates inaccurate readings.	
D34. Dust can create challenges with level measurement due to buildup on level measurement devices and false readings due to particulate. Locate the slurry mix tank level measurement device away from the lime powder inlet and the agitator if possible.	8.2.5
D35. Locate the water inlet below normal liquid level to prevent solids buildup in the tank. Flex hose could be used instead of hard pipe to prevent "build up ball" of scale.	8.2.6
D36. Lime powder should be added to the tank as close to the center of the tank as possible. The inlet should be close to the agitator shaft so that the powder drops into the vortex formed by the agitator, but should not be on the agitator shaft. Lime powder inlet should not be directly over top of the baffles or agitator to avoid product build up.	8.2.6
D37. The slurry tank lime slurry outlet should be raised off the bottom of the tank. A proposed minimum based on anecdotal evidence is 30 cm (12"). This may help prevent plugging of the suction nozzles.	8.2.6
D38. Create a pipeline specification specifically for the lime system including smooth walled hose and Victaulic or clamp style couplings.	9.2
D39. Minimize pressure drop in the slurry piping system. Minimize dead legs in slurry transfer lines. Minimize the slurry transfer line length and direction change in lines to prevent plugging. Where elbows are necessary use long radius elbows. Avoid use of vertical pipelines.	9.2
D40. Avoid reduced pipe diameter sections and instrumentation or controls on the lines to prevent solids buildup and plugging in these locations. If reduced pipe diameters are necessary, reductions must not be so abrupt that they can cause a violent hydraulic disturbance that can result in dewatering and compaction of the lime.	9.2
D41. Solid pipe, flex pipe, or flex hose can be used for the slurry transfer lines. If line plugging is a challenge consider using smooth walled hose for slurry transfer lines to provide easy maintenance, and/or replacement. Consider using hose in the pump suction line between the slurry mix tank and the pump to facilitate cleaning.	9.2.1
D42. Higher velocities have shown a strong correlation with reduced settling in pipes, a slurry velocity between 1.2 m/s and 3 m/s is recommended. Ensure that the proper hydraulic calculations surrounding settling velocity are completed. Higher velocities will require high pressures to overcome losses and therefore will require more expensive equipment. This should be considered in making decisions on pump and pipeline design.	9.2.1
D43. Use VFD's over control valves for slurry dosing control to reduce potential control valve erosion and slurry control issues. Ensure VFDs do not allow slurry velocities to fall below the suggested design minimum of 1.2 m/s.	9.2.1
D44. A permanent water flushing system should be in place for removing slurry from pumps, piping, and valves upon system shut-down. The flushing system should be automatic if shut-down is automatic (Beals, 1976). The flush lines should be connected upstream of the pumps.	9.2.1
D45. Facilities with recirculation lines report more challenges with slurry settling in lines than those without recirculation lines. The use of recirculation lines is not recommended unless site specific design parameters require them.	9.2.1

D46. If recirculation lines are used at the facility, flow should be continuous through the lines to avoid settling. The slurry velocity in the recirculation lines should be between 1.2 m/s and 3 m/s.	9.2.1
D47. If recirculation lines are used lines should be sloped to promote gravitational flow to decrease plugging. Overall line guidelines should be followed, see guideline 39.	9.2.1
D48. If recirculation lines are used place the recirculation line take off at a system high point and as close to the reactor as possible.	9.2.1
D49. Avoid using valves for flow control, see design guideline 43. In the event that a valve must be used for flow control, avoid pinch valves as they are easily eroded and may fail. Use knife gate valves for manual control / isolation. Consider using plug valves if pinch valves are found to be unreliable.	9.2.2
D50. Minimize the number of valves on the transfer lines to reduce erosion and plugging.	9.2.2
D51. Do not use check valves in the slurry transfer system, check valves are prone to becoming plugged and remaining open.	9.2.2
D52. Consider using single block isolation valves to help reduce the number of valves used.	9.2.2
D53. If possible valves should be placed in vertical orientation so that debris falls vertically through the valves during open and closure rather than settling in horizontal connections.	9.2.2
D54. The valves and piping surrounding the slurry feed pump should be designed to allow for isolation and flushing of backup pumps before and after use.	9.2.3
D55. Use a slurry pump, many participants noted that a slurry pump is better than a water pump as slurry pumps don't scale or wear as quickly as water pumps.	9.2.3
D56. Pumps should be sized to maintain a minimum velocity of 1.2 m/s in the transfer lines. If recycle lines are used the pump should be sized to maintain a minimum velocity of 1.2 m/s in the recycle lines.	9.2.3
D57. Water temperature should be as cool as practice. 25°C is an ideal water temperature and a maximum water temperature should be 40°C. Lime solubility decreases as water temperature increases, see Figure 14.	10.2
D58. The lime slurry tank should be treated as a reactor in terms of water quality and chemical interactions. The pH in the tank is typically around 12. The water quality characteristics should be considered to reduce scaling of equipment. Increased impurities will increase scaling challenges.	10.2
D59. Minimize alkalinity in slurry makeup water. This will decrease scaling in the slurry mix tank and downstream of the mix tank. Foaming in the slurry mix tank may also be decreased when alkalinity and hardness are minimized.	10.2

Summary of proposed operational and maintenance guidelines

Guideline	Report section
Silo	
O1. Undertake scheduled verification on the silo measurement device at least once every three months. Operators could adapt this schedule as required for their system.	5.2.1
O2. Perform preventative maintenance on the silo vent filter and the PVRV a minimum of once every three months or approximately every 10 offloads whichever comes first. Operators could adapt this schedule as required for their system. Undertake scheduled verification on the silo measurement device at least once every three months. Operators could adapt this schedule as required for their system.	5.2.2
O3. Be aware of potential changes to flow during loading. Do not use physical flow promoters (vibrators or impactors) while the silo is being loaded from an empty state. This promotes compaction of the lime in the silo, which may decrease the flowability of the lime and result in inconsistent feed rate. If you are operating a small silo consider decreasing mechanical vibration while product is offloading.	5.2.3
O4. If bridging over the rotary valve is an issue, implement a procedure to increase air flowrate through the aeration pads and/or aeration cone.	5.2.3
O5. Caution should be taken not to introduce too much air into the silo. This may create dust and cause product control challenges for control devices. Limit the amount of air introduced to the silo to what is required to ensure flowability.	5.2.3
O6. To prevent moisture from entering the silo and creating level measurement and silo clogging challenges, ensure that the top of the silo is sealed during normal operation, the thief hatch is closed, and all fixtures on top of the silo are properly fastened.	5.2.4
O7. Test the slide gate valve located immediately downstream of the storage silo monthly.	6.2.1
O8. The vent on the hopper must be maintained in order to avoid dust in the workplace.	6.2.2
O9. Implement a PM on the chute from the powder transfer components to the slurry mix tank to prevent plugging. Preventative maintenance should include a visual PM of the chute and the valves surrounding the chute during operator rounds.	6.2.4
O10. If a rotary valve is used at the sole method of lime powder volume control it may need to be changed out frequently due to valve erosion issues, this should be reflected in the PM schedule.	7.2.1
O11. Sample slurry prior to the reactor at a minimum of once per shift to ensure there is lime present in the slurry feed.	7.2.2
O12. Ensure that the slurry mix tank vent is functioning at all times during operation to mitigate dust issues, control moisture upstream of the slurry mix tank, and minimize humidity within the slurry tank vapor space.	8.2.2
O13. The slurry mix tank vent scrubber should be visually inspected monthly. A differential pressure meter across the scrubber could also be used to indicate when full cleanings are required but should not be used as the sole means of determining maintenance requirements.	8.2.2
O14. Use the VFD or butterfly valve on the slurry mix tank vent to adjust the air intake as necessary to avoid plugging.	8.2.2

O15. Consult your equipment supplier prior to making changes to critical slurry tank mixing equipment. Making changes without consultation can create greater system challenges instead of improvements. Particularly, do not remove baffles from the slurry tank.	8.2.3
O16. If splashing due to the agitator is an issue, consider changing the slurry mix tank operating level or decreasing the agitator rotational speed, see design guideline 30. Note that the agitator should remain a minimum of one impeller diameter below the normal liquid level.	8.2.4
O17. Visually inspect the slurry mix tank level measurement device weekly, clean the device as necessary.	8.2.5
O18. Pinch valves used for modulation should be "pulsed" (fully open then fully closed, regulating flow with the duration of closure rather than orifice size) instead of partially opened to preserve lifetime.	9.2.2
O19. Stroke control valves fully open / fully closed monthly to help reduce buildup.	9.2.2
O20. Backup pumps should be isolated and flushed before and after use.	9.2.3
O21. "Start and stop" operation can lead to plugging of the pump suction nozzle. Running a high flowrate with low slurry concentration had been seen to decrease pump suction nozzle plugging.	9.2.3

2.0 Introduction

High calcium hydrated lime ($Ca(OH)_2$) is commonly used in water treatment to neutralize acidic solutions and to reduce a water's hardness and associated alkalinity. Benefits of softening water include reducing dissolved minerals and scale-forming tendencies, removing heavy metals, removing certain organic compounds and total organic carbon, and reducing silica. In thermal enhanced oil recovery systems lime is used in conjunction with MgO to increase the reactor pH to facilitate silica removal, improve sludge consistency, and to reduce hardness.

MgO and hydrated lime share some physical similarities and the design of the handling systems share many key components. Building on these similarities, together with previous successes investigating MgO handling system guidelines (WaterSMART, 2014), a case emerged for studying the lime handing system. This report focuses on the use of lime for thermal enhanced oil recovery systems in Alberta.

As a portion of the water treatment process in the oil sands, lime is used to neutralize process water (produced water and makeup water), to meet requirements for boiler feed water quality. The majority of thermal enhanced oil recovery facilities in Alberta currently have a lime handling system in their water treatment process. The operation and maintenance of the diverse lime handling systems pose numerous challenges to facility operators.

Although many challenges are common across the sector, operators have tended to manage them on a plant-by-plant basis with their equipment suppliers and engineering consultants. This approach presented an opportunity to build on the success of the MgO guidelines by sharing knowledge within the industry on potential mitigation options, to address challenges with current systems and develop guidelines for system design and operation to improve the operation of existing and new lime handling systems.

Recognizing this opportunity, Graymont retained Alberta WaterSMART (WaterSMART) to develop a set of design and operational and maintenance guidelines. A collaborative approach involving workshops and interviews with 10 owner companies, a hydrated lime supplier, a MgO supplier, three lime system equipment suppliers, and one engineering company was used to develop guidelines. This enabled operator-based collaboration that focused on operator potential for improvement. While suppliers and consultants have a significant impact on the design and operation of a system, owners have the greatest influence through specifications development and implementation.

The project team engaged participants in workshops, information gathering questionnaires and interviews to develop the lime handing system guidelines. The workshop, interviews, and information collected as part of this project indicates the categories of design and operation and maintenance should be addressed. The results of the project are presented as guidelines for each category.

A guideline is a statement used to determine a course of action. A guideline aims to streamline particular processes according to a set routine or sound practice. By definition, following a guideline is never mandatory; guidelines are not binding and are not enforced. The guidelines in this report are for consideration only and should not be considered final design principals.

This report has two main purposes:

1) To serve as a resource for operators wishing to develop a greater understanding of the systems, potential system challenges, and how they can be addressed, and
2) To explain how and why the guidelines were developed.

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3.0 Background

This section describes the major components in the lime handling system and the neutralization chemistry of lime systems, reviews the lime handling system design process value chain, and summarizes some of the major challenges associated with the lime systems. Because this work started with the MgO guidelines as a baseline this section also identifies key commonalities and differences between the lime and MgO processes.

3.1 Lime handling system overview

Lime is used in thermal enhanced oil recovery facilities to neutralize process water (produced water and makeup water) as one component of a process to meet requirements for boiler feed water quality. Lime is used in a powder form and is mixed with makeup water onsite to produce a slurry. This slurry and the process water are then combined in a warm or hot lime softener or an evaporator to increase the solution's pH and to remove alkalinity and associated hardness.

In this report the warm or hot lime softener or evaporator is referred to as the reactor. As is the case for MgO slurry systems, lime slurry systems can include as many as six major components.

The system can be configured in many different ways, and not all of the configurations include all six components, which are:

- Lime powder storage silo
- Rotary transfer valve
- Lime hopper
- Screw conveyor
- Slurry mix tank, and
- Feed pump.

Figure 1 shows a schematic of the common configuration of a lime handling system.

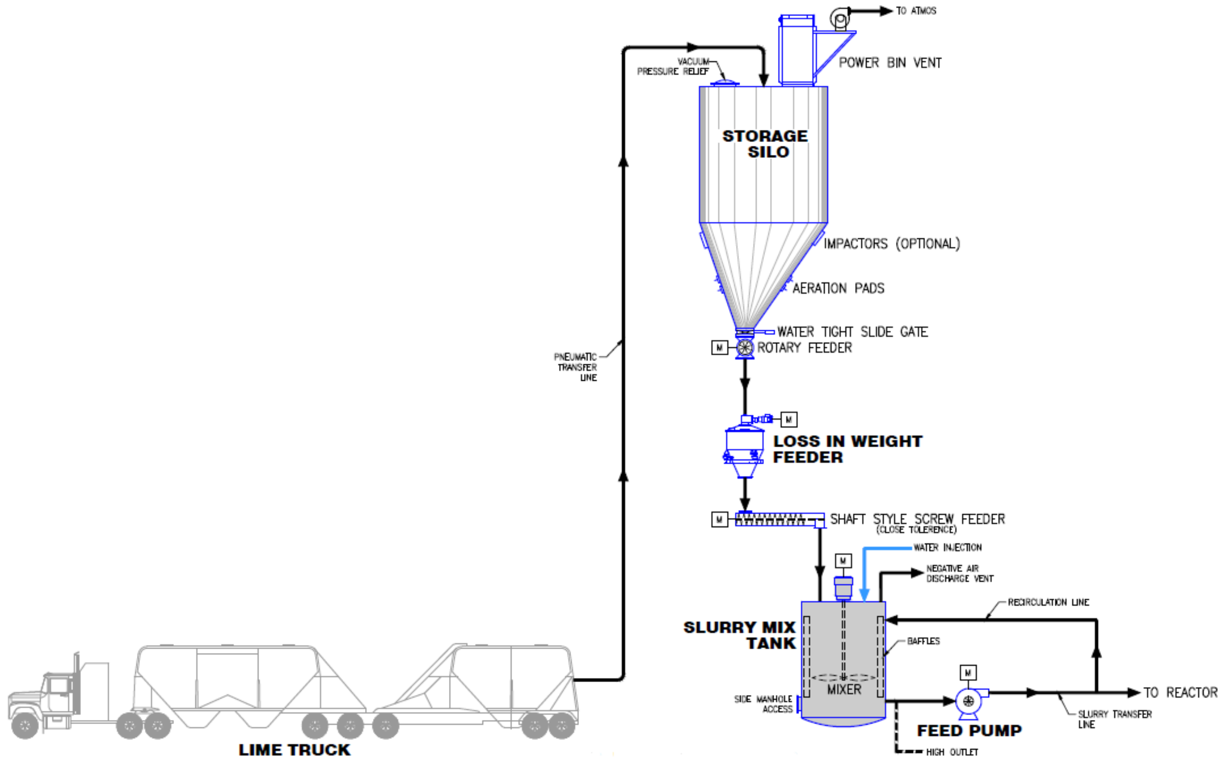

Figure 1 – Typical lime handling system (diagram provided by Graymont Western Canada Inc.)

The lime powder is delivered to the facility by a powder supply truck and is transferred from the truck to the storage silo pneumatically; the typical transfer flowrate is from 17m^3/min (600 cfm) to 24 m^3/min (850 cfm). Spatially, the silo is typically located above the slurry mix tank. Typical silo components are, at a minimum, a filter and a level transmitter. Many silos have pneumatic or mechanical impactors on the silo outlet (the silo cone) as well as air injection pads or an aeration cone. These components are designed to facilitate flow of the lime powder out of the silo.

The lime powder is transferred from the silo to the slurry mix tank using either a volumetric or a mass based transfer control approach.

A volumetric transfer system may employ a rotary valve, a volumetric hopper, a screw conveyor, or a combination of these components. A mass based transfer control approach employs a loss-in-weight hopper. Loss-in-weight hoppers can be used either to control transfer of product out of the silo to another transfer device, and/or to measure lime powder dosing to the slurry mix tank. Where hoppers are used as the dosing device, they are followed by a screw conveyor. These components, either volumetric or mass-based, are used to dose lime powder to the slurry tank. See Sections 6.0 and 7.0 for a discussion of the components used to transfer the hydrated lime to the slurry tank and the associated proposed design guidelines.

The transfer device feeds the product to the slurry mix tank; this transfer usually takes place through a chute, however sometimes it takes place through an air gap. In the slurry mix tank, makeup water is mixed with the hydrated lime powder to create a slurry. The mix tank typically contains an agitator and baffles to ensure proper mixing. Other typical components of the slurry mix tank are a venting system, clean out ports (manholes) and a level transmitter. See Section 7.0 for a discussion on slurry mix tanks and the associated proposed design guidelines.

The slurry is transferred from the mix tank by a feed pump. It is pumped through slurry transfer pipelines to the downstream reactor. Recirculation piping may also be used to recirculate the slurry back into the slurry mix tank. See Section 8.0 for a discussion on the slurry transfer lines and the feed pump and the associated proposed design guidelines.

3.2 Commonalities and differences between lime and MgO handling systems

In Alberta's thermal enhanced oil recovery industry, both MgO and lime are used to treat process water to an acceptable quality for use as boiler feed water. Inherently, there are numerous commonalities between the two processes. These commonalities highlight the obvious opportunity to develop lime handling system guidelines; to emulate the existing MgO handling system guidelines (WaterSMART, 2014):

- Delivery method is via truck, with product transferred into storage pneumatically
- Both products are subject to fluidization
- Both products readily absorb moisture from the air
- The goal is to transfer the slurries into the WLS/HLS
- Water quality used for lime mixing and MgO slaking phase is critical, and
- Solubility for both lime and MgO decrease with increasing temperature.

Although the points above help streamline the analysis of lime handling systems based on past experience with MgO handling systems, there are key differences between these two systems which must be integrated into the lime guideline development process:

- High calcium hydrated lime, as used in the oil sands, is already slaked when delivered to the site, at site it is mixed with water
- MgO must be slaked on-site to form $Mg(OH)_2$, where the goal is to minimize slaking prior to the WLS/HLS
- Water temperature plays a different role in the lime and MgO handling system
- Hydrated lime is more stable in the presence of moisture and CO_2 compared to dehydrated products such as MgO
- Approximately three times more lime is used at site compared to MgO, and
- Lime is a finer powder than MgO, leading to differences in the amount of hammering and/or air injection required at the silo.

3.3 Lime design process value chain and stakeholder roles

Although the lime system and process components play a large role in how the system functions, the design process, the parties involved, and their roles and responsibilities also affect the system's functions and are important to understand. The parties involved include owners, operators, consultants and suppliers, and each has a different impact through their varied contribution to design, construction, and operation. Table 1 lists all the parties involved in the design process value chain and their roles and responsibilities.

Suppliers and consultants have a significant impact on the design and operation of a system. The specifications provided by the facility owner to purchasing, or to the design engineer who in turn provides specifications to purchasing, are the most effective way to ensure important parameters are translated into the hardware. In the absence of owner's specifications, the process for tender and award of the equipment and design contract may create a situation where suppliers provide the lowest cost design to win the contract, without considering long term system operability. For example, if the agitator or tank specifications are not detailed enough, the supply chain process may not provide the most efficient or effective equipment.

Owners have the greatest influence through development and implementation of specifications and standard operating procedures to ensure the appropriate considerations are made from the beginning of the design process through to daily operation of the system.

The primary direction from this project is for owners to use the proposed guidelines in this report to develop their own requirements specific to lime systems. Further, it is imperative owners take action to effectively communicate guidelines and subsequent internal specification to design engineers and purchasing departments.

Table 1 – Lime design process value chain

Stakeholder	Roles and responsibilities
Facility Owner	• Develops specifications and provides to EPC
Engineering, Procurement, Construction (EPC) company (e.g., Vista Projects)	• Design based on owner specifications, including: o mixing chemistry o control philosophy and dosing system o major system components • Provides owner specifications to equipment package supplier • Receives package supplied by equipment package supplier • Constructs lime handling system based on drawings and specifications • Commissioning
Equipment Package Supplier (e.g. STT Enviro Corp)	• Receives owner specifications • Design based on owner specifications, including physical mixing • Provides owner specifications to specific component equipment suppliers to use in the package system • Commissioning • Conducts trouble shooting when necessary • Provides recommendations for improvements to systems
Specific Component Equipment Supplier (e.g. MixTech)	• Provides specific components based on direction from Equipment Package Supplier
Lime supplier (e.g. Graymont)	• Develops the powder from raw materials, and provides the product at specification to the owner
Independent lime transporter (via trucks)	• Loads, transports, and off-loads lime from trucks for delivery to the facility • Responsible for ensuring on-spec lime powder is delivered to the silo
Facility Owner/Operator	• Quality assurance testing of product when it arrives on site • Conducting operations and maintenance of the lime handing systems • Undertakes preventative and as-needed maintenance on lime handing systems • Corresponds with the lime Transporter, lime supplier, EPC and Equipment Package supplier, as required to undertake troubleshooting

3.4 Lime neutralization chemistry

In wastewater processes, lime can refer to quicklime or hydrated lime. The formation of each from limestone is broken down as follows:

1) Limestone + Heat → Quicklime + Carbon Dioxide
2) Quicklime + Water → Hydrated Lime + Heat.

Hydrated lime, $Ca(OH)_2$, is delivered to thermal enhanced oil recovery facilities for use in water treatment processes, so slaking is not required on-site, as such it is not addressed in this report. Unlike MgO, lime does not directly remove silica from process water; instead, lime raises the pH of the water to facilitate silica removal by other agents. At higher pH (9 and greater) the softening of process water occurs through the precipitation of calcium and magnesium. This promotes the removal of silica through adsorption by or entrapment within magnesium hydroxide, which is formed through MgO hydration. Thus the relevant chemistry for lime processes is the mechanism by which lime neutralizes acidic solutions.

Unlike MgO, lime is slightly soluble in water. Any lime which dissolves will dissociate into Ca^+ and $2OH^-$, both of which react with their corresponding acidic equivalents of opposite charge. As these reactions occur, more $Ca(OH)_2$ enters solution and dissociates, allowing further neutralizing reactions. The solution pH is increased through the introduction of $Ca(OH)_2$. In addition to the concentrations of ion species present, reactivity depends on particle size, where coarser particles are slower to react and may remain as sludge—as the available acidic ions are consumed by reaction with the basic ions of finer $Ca(OH)_2$ particles. The process by which $Ca(OH)_2$ is produced dictates material coarseness and is therefore manufacturer dependent.

3.5 Lime handling system challenges

Challenges associated with specific components are discussed in the relevant sections of this report. Some of the most common system challenges include:

- Product level measurement and control in the lime storage silo
- Settling of lime solids in the bottom of the slurry mix tank
- Splashing from water inlet or slurry agitator in the slurry mix tank resulting in solids buildup on the slurry mix tank walls
- Plugging of the piping upstream and downstream of the slurry pump due to scaling and settling of lime slurry
- The presence of moisture in the equipment causing clumping of the hydrated lime powder, which creates inconsistent delivery and clogs transfer systems and equipment, and
- Dust control.

A number of variables can impact these and other component-specific challenges, including but not limited to:

- Source water quality and temperature
- Slurry mix tank venting system design and maintenance
- Delivery location of lime and raw water to slurry mix tank
- Slurry mix tank and baffle sizing and configuration
- Agitator impeller size, type and speed, and
- Process piping:
    - pipe type (hard pipe versus hoses)
    - pipe size and configuration
    - slurry velocity, and
    - valve type.

The assessment of these and other variables in numerous thermal enhanced oil recovery systems provided insight into what makes a system operate effectively. The specific variables considered are outlined in the relevant sections of this report.

4.0 Guideline development methodology

A collaborative approach involving 10 owner companies, a hydrated lime supplier, a MgO supplier, three lime system equipment supplier and one engineering company was used to develop the guidelines in this report. This allowed for an operator based collaboration focusing on operator potential for improvement. As outlined previously, while suppliers and consultants have a significant impact on the design and operation of a system; owners have the greatest influence through the development and implementation of their specifications.

The thermal enhanced oil recovery facility operators participated in two workshops and one-on-one interviews with WaterSMART. Company information was collected and analyzed to identify trends in challenges, solutions, and optimal design and operation, and to develop the proposed guidelines.

First workshop

The goal of the first workshop was to explain the project context to participants and identify challenges operators experience related to lime handling systems that should be addressed through the development of system guidelines. Further, as MgO dosing system guidelines acted as a baseline for the lime guidelines, the MgO guidelines were discussed during the workshop. During this workshop various companies openly discussed challenges they had experienced with their lime handling systems, likely causes of these challenges, and solutions they had tested or implemented in their design and operation. Participants were also asked to examine the MgO guidelines and identify if the guidelines were relevant to lime handling systems, if the guidelines needed to be changed for lime handling systems, or if the guidelines were not relevant to lime handling systems.

One-on-one interviews

Based on findings from the first workshop, a one-on-one interview package was developed. This package was designed to uncover challenges each individual facility was experiencing, why they experienced these challenges, and what they had done in to mitigate these challenges. Participants were also asked to provide design information in the hope this information could be correlated to challenges or lack therefore. Design information can be found in tables throughout this report and in the equipment matrix in Appendix 1.

Fourteen facilities were analyzed. One additional facility participated however the facility was not operational therefore it was not included in the formal analysis; information from this facility was included anecdotally only. Five participating owner companies included two facilities in the work. The facility numbering stays consistent throughout the analysis.

Following the one-on-one interviews, the information related to challenges, causes and solutions was collated into tables, along with operation and design information, to identify trends and connections between challenges, causes and design. These trends and connections have been documented as proposed lime handling system guidelines in this report.

Second workshop

At the second workshop, WaterSMART presented the proposed guidelines and obtained additional information and feedback on specific challenges and potential solutions, as well as feedback on a useful format and information to be included in the proposed guideline document. Based on the workshop results, a report entitled *Hydrated lime ($Ca(OH)_2$) handling system design, operation, and maintenance toolkit for thermal enhanced oil recovery* was prepared. It draws on information from this report and can be used as a quick reference for operators in developing specifications and standard operating procedures.

5.0 Lime storage silo

The lime silo stores the high calcium hydrated lime prior to the slurry mixing process. The product is transferred pneumatically into the silo by a third party (delivery truck). The powder is transferred out of the silo either volumetrically or based on weight. It is transferred using one of, or a combination of the following components: a rotary valve, a volumetric or loss-in-weight hopper, and a screw conveyor. These components are discussed in Section 5.0 of this report.

Silos in the facilities analyzed for this work ranged in capacity from 150 – 550m^3 with and average capacity of 270m^3. The silo is a large vertical sealed tank with the top outside of the water treatment process building. The silo typically includes a level measurement system, a pressure vacuum relief valve (PVRV), a dust collector mounted atop the silo, pneumatic or mechanical impactors, and air injection pads or an air injection pad.

5.1 Results

Table 2 displays the data collected regarding lime storage silos. The core equipment and process components and challenges experienced at each facility are shown. The major challenges in relation to the storage silo and silo components were:

- Product level measurement and control
- Filter plugging and/or PVRV popping during product offload
- Inconsistent lime feed rate from the silo
- Lime flow through during offload, and
- Failure of rubber reducer / wear on the equipment.

Additional challenges were:

- Moisture exposure causing plugging or solids formation
- Bridging over the rotary valve, and
- Clumps in the lime product or changes in lime density causing inconsistent feed.

Figure 2 illustrates the number of facilities that experienced each challenge identified with the lime powder silo, there were 14 facilities analyzed.

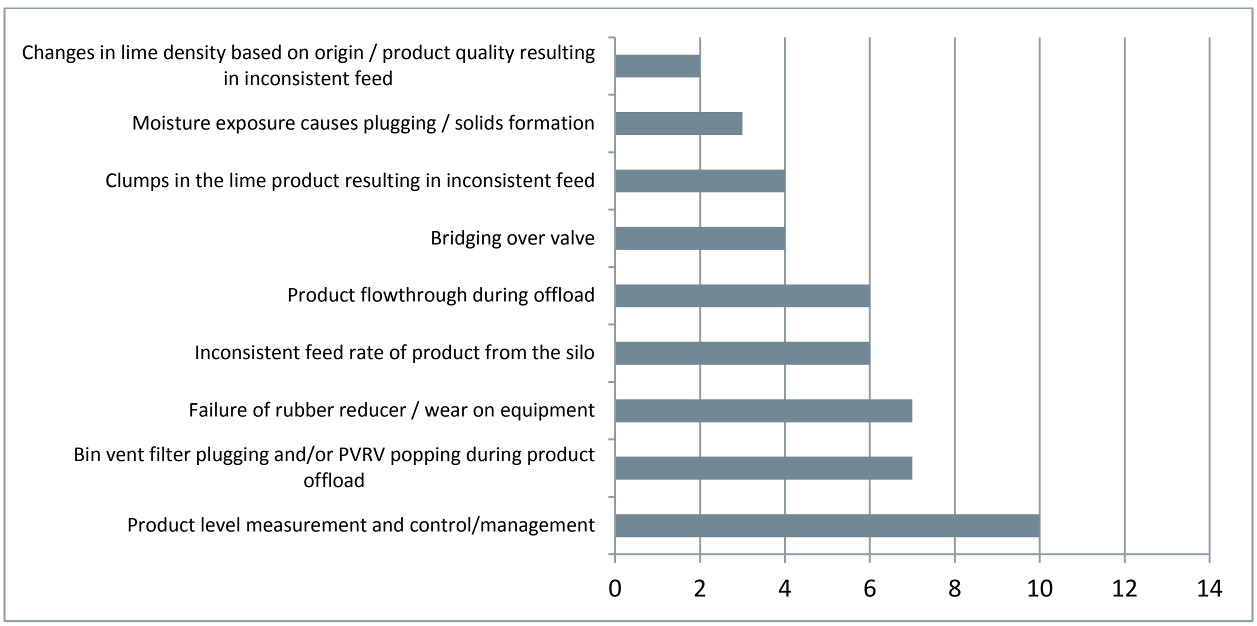

Figure 2 – Challenges associated with lime silo

The silo components subject to the most challenges were the level measurement device, the bin vent filer, the rubber reducer, and the downstream rotary valve.

Table 2 – Equipment and challenge matrix – lime storage silo

				Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Core equipment & Process Components	Product Transfer	Is there a target box?		No	No	No	No	No	No	Yes	Yes	Yes	No			No	No
		What are the PVRV settings?	Pressure (kPag)	0.86	0.86	1.914	0.86	1.72	1.72	1.7	1.7	2.59	0.86	1.7	0.86	0.86	
			Vacuum (kPag)	-0.2	-0.2	-0.215	-0.22	-0.22	-0.22	0.17	0.17	-0.17	0.17	-0.2	-0.215	0.2	
	Level measurement	Works well (accurate)		-	-	-	-	X	X	-	-	-	-	-	-	-	-
		Works well enough to show trends		-	-	X	X	-	-	X	X	X	X	X	X	-	X
		Works sometimes		-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Does not work		X	X	-	-	-	-	-	-	-	-	-	-	X	-
		Guided Wave Radar		X	X	-	-	-	-	-	-	-	-	X	X	-	-
		Radar		-	-	-	-	-	-	-	X	X	X	-	-	X	-
		Cone Radar		-	-	-	-	X	X	-	-	-	-	-	-	-	-
		Ultrasonic		-	-	-	-	-	-	X	-	-	-	-	-	-	X
		Load cell		-	-	X	X	-	-	-	-	-	-	-	-	-	-
		Air purge on measurement device		-	-	-	-	X	X	-	-	-	-	-	-	X	-
		PMs		None	None	Yes - frequency unknown	Yes - frequency unknown	None	None	Yes - 2 weeks	Yes - 3 months			None	None	None	None
	Downstream valve type	Knife / Gate isolation valve		X	X	X	X	X	X	X	X	X	X	X	X	X	X
		Rotary		X	-	X	X	X	X	X	X	-	X	X	X	X	X
		Hopper		X	-	-	X	X	X	-	-	X	-	X	-	X	X
		Screw Conveyor		X	X	X	X	X	X	-	-	X	-	X	-	X	X
	Silo Bin Vent Filter	Bag House		-	-	X	X	X	-	-	-	X	X	-	-	-	-
		Cartridge style		-	-	-	-	-	X	X	X	-	-	X	X	X	-
		Bin Filter		-	-	-	-	-	-	-	-	-	-	-	-	-	X
		"Sock Filter"		X	X	-	-	-	-	-	-	-	-	-	-	-	-
		Capacity of filter (m^3/h)						2125	1700			1274	1428		2,549		
		Filter area (m^2)		24	26		26		26	24	24.5		26	24	24.5	24	
		Design air-to-cloth ratio (m/min)							1.09				0.92		1.73		
		Filter material		Polyester Type	Carbon steel		Polyester PTFW Coated	Cartridge	Polyester felt			Polyester Sateen "Snap-in" bags	Synthetic fibre	Spun bound polyester	Polypleat	Polyester cartridges	Polyester
	Flow Promotion	Aeration cone		No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No[1]	No	Yes
		Aeration pads		Yes	Yes	Yes	Yes (8)	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes (8)
		Pneumatic Impactors		-	-	X	X	X	-		-	-	-	X	-	X	X

		Mechanical Impactors	X	X	-	-	-	X		-	-	-	-	X	-	-
	Silo Design	Silo diameter (mm)	4690 OD	5630 ID	6566	5630	9060	7970	3962	3937	4267	4267	4240	4240	6560	3750
		Silo capacity (m^3)	220	198.9		325	554	554	103	103	200	266	241	254	379	127.5
		Silo cone angle			60	60	60	60	60	60	60	60	60		26	70
		Number of powder outlets	1	1	2[2]	2[2]	1	1	1	1	1	1	1	2	1	1
	Silo Vent PMs	Are there PMs?	Yes	Yes	Yes	Yes	No	No							No	No
		Frequency	6 months	6 months	Annual	Annual	-	-							-	-
	Vent on slurry tank	Is there a vent?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		Vacuum on vent	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No
		Wet scrubber on vent	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	No
		Vent fan in line or induced	Induced (venturi)	Induced (venturi)	-	Induced	Induced	Draft fan (not induced)	Induced draft fan	Induced draft fan (not in-line)	-	Natural circulation / convection	Eductor (not in-line)	Eductor (not in-line)	Venturi	-
		Vents outside	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
Challenges	Product level measurement and control/management		Yes	Yes	Yes[3]	Yes[3]	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	Bin vent filter plugging and/or PVRV popping during product offload		Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No
	Moisture exposure causes plugging / solids formation		No	No	Yes	Yes	No	No	No	No	Yes	No	No	No	No	No
	Inconsistent feed rate of product from the silo		No	No	Yes	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No
	Product flow through during offload		No	Yes[1]	No	No	Yes	No	Yes	Yes	No	Yes	No	Yes	No	No
	Bridging over valve		Yes	Yes	Yes	Yes	No	No	No	No	-	No	No	No	No	No
	Clumps in the lime product resulting in inconsistent feed		No	No	Yes	No	No	No	No	No	Yes	No	Yes	Yes	No	No
	Changes in lime density based on origin / product quality resulting in inconsistent feed		No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	No
	Failure of rubber reducer / wear on equipment		Yes	Yes	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	No

Notes:

1. This issue was fixed with the installation of a knife valve and a procedure to close the valve during product offload.
2. Dual train system - each outlet leads to a different HLS.
3. Load cells need to be calibrated.

5.2 Analysis

The following section addresses the majority of the challenges associated with the lime storage silo. Note, because some challenges are more closely associated with the system components downstream of the silo, these challenges are addressed in Section 5 “lime transfer from storage silo to slurry mix tank”.

5.2.1 Level measurement

Level measurement of the hydrated lime powder in the silo was a challenge for 10 of the 14 facilities analyzed (71%). While level measurement was the most common challenge in the silo many facilities noted it was not the most pressing challenge in their lime handling system.

Table 3 summarizes the type of level measurement used by the facilities in the analysis. Nine out of 14 facilities (64%) indicated that while the level measurement on the silo was not exact it was sufficient for the purpose of providing inventory control. Three out of 14 facilities (21%) indicated the level measurement on the silo did not work and only two of 14 facilities (14%) indicated the level measurement on the silo worked well.

None of the facilities analyzed used the silo level measurement as a key systems control trigger, therefore this challenge is not associated with downstream challenges.

Table 3 – Summary of silo level measurement devices

Type of level measurement	Facilities with this type (out of 14)	Functionality of level measurement		
		Works well	Works well enough to show trends	Does not work
Guided wave radar	4		2	2
Load cell	2		2[1]	
Cone radar with air purge	2	2		
Ultrasonic	2		2	
“Radar”	3		3	
“Radar” with air purge	1			1

Notes:

1. If the load cell were properly calibrated it would work well, however the silo must be empty in order to calibrate the load cell.

Most facilities employ some form of radar level measurement device. The facilities with cone radar measurement devices with an air purge report the highest level of accuracy in silo level measurement and these two facilities have the same owner. Facilities using other forms of level measurement devices, such as guided wave radar, radar, ultrasonic, and load cells report that level measurement is accurate enough for inventory control. Facilities using guided wave radar report the highest number of issues – with two of four facilities noting their level transmitter rarely works.

Below are some notes reported during one-on-one interviews regarding level measurement:

- The performance of guided wave radar is sensitive to how the transmitter and cable are installed. The location of the sensor mounting nozzle in the silo must conform to the instrument manufacturer's requirements. Furthermore the cable in the guided wave radar may be susceptible to caking of lime powder. Two facilities noted that they had changed from guided wave radar to cone radar with an air purge, and they felt that the cone radar with air purge was must more accurate than the guided wave radar.
- The presence of dust and dusty buildup reduces the accuracy of ultrasonic level measurement devices.
- One facility noted that they had used ultrasonic in the past but did not find that it was accurate.
- The highest success is reported with cone radar level measurement with an air purge.
- Load cell or weight scale level measurement is accurate if properly calibrated and understood, however they present challenges due to the inability to calibrate. Calibration requires a known weight of powder in the silo or ideally and empty silo. Due to continuous operation and low likelihood of silo redundancy, continual operation limits the opportunity for proper calibration.

Proposed design guideline:

D1. Use the silo level measurement device for inventory control only, do not use it as a means for measuring lime dose to the slurry mix tank. Using the silo level measurement device for lime dosing will be less accurate and may cause ongoing system operating and performance issues.

Four of the analyzed facilities had scheduled preventative maintenance schedules (PMs) on the silo measurement devices. In two of the facilities the frequency of the PM was unknown, in the other facilities the frequency was every two weeks and every three months. All four of these facilities indicated that their level measurement devices worked well enough to show trends. There is no definitive trend in PM frequency regarding level measurement devices, however a PM is suggested to ensure that level measurement in the silo is as accurate as possible.

Proposed operational and maintenance guideline:

O1. Undertake scheduled verification on the silo measurement device at least once every three months. Operators could adapt this schedule as required for their system.

5.2.2 Dust collector

Seven out of 14 facilities (50%) indicated plugging of the silo filter was a challenge. All of the lime storage silos had a vent; the most common vent types include a bag house, a cartridge style vent, and a sock filter. No trends were identified between vent type and vent plugging – among all facilities and all vent types approximately half of the participants indicated they had challenges with vent plugging.

The National Lime Association (1995) notes the most critical variable in a dust vent system is the filter volume required to adequately capture the dust from the emission source. The pneumatic transfer of the lime from the truck to the silo was identified as the most significant source of dust in the silo.

Proposed design guideline:

D2. Size the silo vent to match:

- the pneumatic flow rate expected from the lime transfer from the truck into the silo, and
- air injection into the silo.

Lime is transferred pneumatically from trucks at rates ranging from 17m^3/min (600 cfm) to 24 m^3/min (850 cfm).

It was noted during the second workshop that the silo vent should not be an active vent; where an active vent is defined as a vent that pulls a slight vacuum. An active vent will pull lime dust from the silo and will lead to increased plugging issues in the silo vent filter.

Other important metrics surrounding filter design are the filter area and the air to cloth ratio. The filter area was reported in 10 out of 14 facilities, and the air to cloth ratio was calculated in three facilities based on filter area and vent capacity. Facilities indicated silo filter areas between 24 m^2 and 26 m^2 and air to cloth ratios of 0.9 m/min – 1.7 m/min. Documented air to cloth ratios varied considerably, however it was noted that facilities should air on the side of caution and have a high air to cloth ratio; higher ratios will not hinder the efficacy of the filter.

Proposed design guideline:

D3. Have a filter on the silo vent. For hydrated lime a minimum filter area of 0.09 m2 (1 sq. ft.) of cloth area per 0.085 m3 (3 cu. ft.) of air is recommended. When Jet Pulse dust collectors, involving compressed air bag cleaning, are used, they operate at air to cloth ratios between 3.5:1 and 4.5:1, depending on the fineness of the lime (National Lime Association, 1995).

If the pneumatic transfer of the lime product from the truck to the silo presents an issue some facilities have had success with the installation of a target box at the point of pneumatic transfer. Three of 14 facilities had a target box. Two facilities, with the same owner, installed target boxes specifically to mitigate silo over-pressuring during pneumatic product transfer.

Four facilities indicated that PMs are carried out on the silo vent filter at their facility. Four facilities reported that they did not have PMs in place, but acknowledged that PMs would be useful. The remaining six facilities were unsure of whether PMs existed. PMs carried out on the silo vent filter will decrease dust in the system, this may also improve the accuracy and longevity of the level measurement device in the silo.

Proposed operational and maintenance guideline:

O2. Perform preventative maintenance on the silo vent filter and the PVRV a minimum of once every three months or approximately every 10 offloads whichever comes first. Operators could adapt this schedule as required for their system. Undertake scheduled verification on the silo measurement device at least once every three months. Operators could adapt this schedule as required for their system.

5.2.3 Flow promoters

Flowability of lime out of the silo can be increased by vibration of the silo cone or injection of air into the silo. The four main methods to increase flowability are: aeration pads, an aeration cone, pneumatic impactors, and mechanical impactors. Of the facilities, 13 out of 14 assessed (93%) had a minimum of one of these flow promotor and many facilities had a form of air injection as well as a form of impactor. All facilities with mechanical impactors also had some means of air injection into the silo.

Figure 3 summarizes the flow promoters used at the facilities analyzed as part of this study.

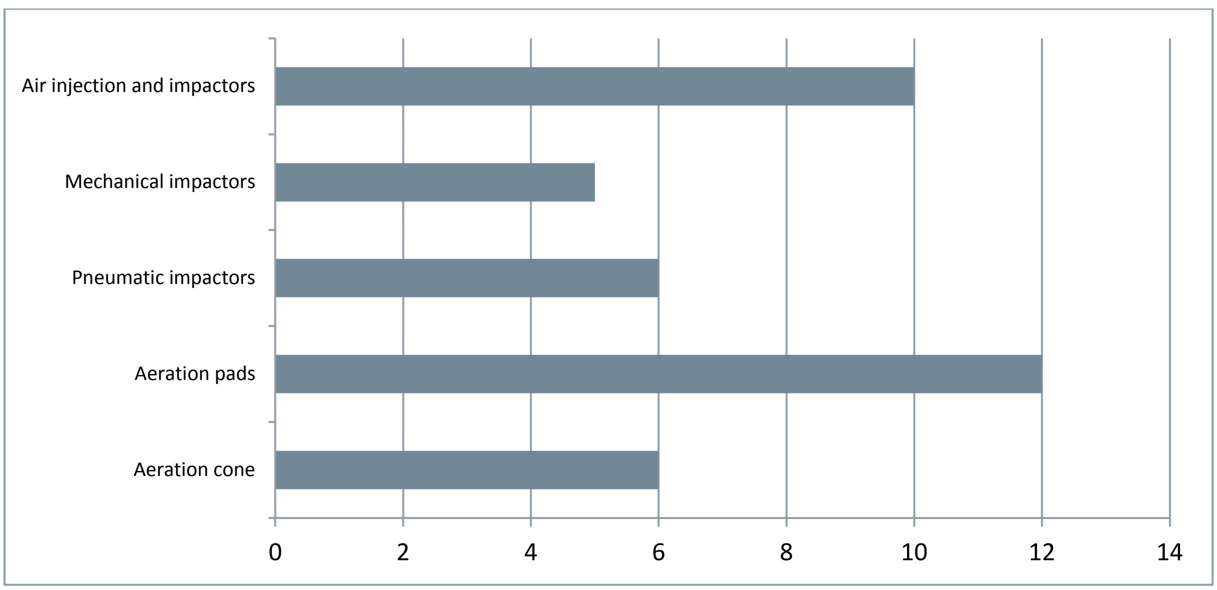

Figure 3 – Flow promotion out of the storage silo

Proposed design guideline:

D4. Include a means of air injection (aeration pads / aeration cone) into the silo to increase the flowability of the lime product and avoid bridging over the silo outlet. Air should not be injected into a silo if there is no rotary valve downstream of the silo. See proposed design guideline number 5 for information regarding mechanical impactors.

It was noted air injection should not be used in systems that do not have a rotary valve. If the system does not have a rotary valve to control the volume of lime transferred out of the silo then the air may fluidize the lime causing it to escape the silo at an uncontrolled rate.

Seven out of 14 facilities (50%) indicated failure of the silo reducer or wear on the silo reducer were a challenge. This challenge was associated with the mechanical impactors most silos have at the silo outlet, to promote the flow of the lime powder. Three out of four facilities (75%) with mechanical impactors reported wear on the silo reducer, whereas only four out of 10 of facilities (40%) without mechanical impactors reported this challenge.

Although impactors may increase wear on the silo they can also be a vital tool in increasing the flow of the lime out of the silo. The risks of using impactors should be well understood; impactors can cause vibrations throughout the system. To mitigate the wear caused by impactors flexible connections can use used; flexible connections will not transfer the vibrations to the remainder of the system. Additionally, vibrations caused by impactors can pack the hydrated lime powder. Impactors or vibrators should not be used while a silo is being filling from an empty state. The risk of packing the lime can be mitigated by operating the impactors with an interrupter which produces a one to two second vibration every five to 10 seconds (National Lime Association, 1995).

Mechanical impactors should not be used on silos that have multiple outlets, but only have one outlet working at a time. If one outlet is flowing and the other is not, the lime sitting in the outlet that is not flowing may become packed down and fail to flow.

Proposed design guideline:

D5. Mechanical impactors should not be overused, their use should be optimized in conjunction with the use of an air injection, see proposed guideline number 4. Mechanical impactors can cause vibrations through the system, when they are used care should be taken to understand the risks caused by vibration.

Proposed operational and maintenance guidelines:

O3. Be aware of potential changes to flow during loading. Do not use physical flow promoters (vibrators or impactors) while the silo is being loaded from an empty state. This promotes compaction of the lime in the silo, which may decrease the flowability of the lime and result in inconsistent feed rate. If you are operating a small silo consider decreasing mechanical vibration while product is offloading.

O4. If bridging over the rotary valve is an issue, implement a procedure to increase air flowrate through the aeration pads and/or aeration cone.

O5. Caution should be taken not to introduce too much air into the silo. This may create dust and cause product control challenges for control devices. Limit the amount of air introduced to the silo to what is required to ensure flowability.

5.2.4 Moisture control

Four out of 14 facilities (29%) experienced issues with moisture control in the silo causing plugging and solids formation. One facility noted moisture in the silo originated from the top where the thief hatch was not properly fastened. To ensure there is no moisture entering the silo through the top, it is important to ensure the top of the silo is sealed.

Proposed operational and maintenance guideline:

O6. To prevent moisture from entering the silo and creating level measurement and silo clogging challenges, ensure that the top of the silo is sealed during normal operation, the thief hatch is closed, and all fixtures on top of the silo are properly fastened.

The slurry mix tank is another source of moisture within the lime handling system. Without a properly functioning vent on the slurry mix tank the vapor from the makeup water is not properly expelled from the system and thus has the potential to become entrained in process equipment upstream of the slurry mix tank. Venting on the silo will not mitigate this moisture control challenge; this moisture issue must be mitigated with a properly designed and maintained vent on the slurry mix tank. For more in-depth discussion regarding the slurry mix tank and the slurry mix tank vent see Section 8.0.

The placement of the system components upstream of the slurry mix tank may also help mitigate moisture control issues. It is suggested that if the lime storage silo is not placed directly above the slurry mix tank moisture control issues may be mitigated. There is no data available from participating lime handling facilities to support this guideline, however past data gathered while analyzing magnesium oxide handling facilities (WaterSMART, 2014) supports this guideline; furthermore this guideline was discussed in the lime handling system workshops and participants agreed that it applied to lime handling systems.

Proposed design guideline:

D6. Do not place the process components upstream of the slurry mix tank directly above the tank. This will reduce the travel of water vapor from the tank to these components, preventing lime formation buildup within these process components.

6.0 Lime transfer from the storage silo to the slurry mix tank

Lime is transferred from the storage silo to the slurry mix tank either volumetrically or using a mass based approach. One or several of the following components are used to transfer the lime powder from the silo to the slurry mix tank:

- Rotary valve
- Loss-in-weight hopper
- Volumetric hopper, and
- Screw conveyor.

If a rotary valve is used it is generally directly downstream of the storage silo and should be separated from the silo by an isolation valve. If there is a hopper it is generally positioned below a rotary valve, and is generally followed by a screw conveyor. A screw conveyor is generally used in conjunction with a rotary valve and/or a hopper, however in some instances it is used as the sole lime powder transfer component.

Following the transfer device the lime powder is transferred through a chute or an air gap to the slurry mix tank. The chute is made of hard pipe, rubber, or fabric.

The hydrated lime powder transfer components are discussed individually here, as these components are also an integral part of the lime powder dosing and control system they are also discussed as a system in Section 6 - Lime handling system dosing and concentration control.

6.1 Results

Table 4 displays the data collected regarding the lime transfer from the storage silo to the slurry mix tank. The core equipment and process components as well as challenges experienced at each facility are shown. The major challenges in relation to the lime transfer from the storage silo to the slurry mix tank were:

- Rotary valve erosion issues
- Rotary valve flow through

- Repeatability of volume fed by the rotary valve
- Foreign objects entering the silo and getting stuck in the rotary valve
- Difficulty achieving low feed rate through the screw conveyor
- Maintenance issues with the screw conveyor
- Issues with feed rate of the screw conveyor, and
- Plugging of the chute from the screw conveyor to the slurry mix tank.

Additional challenges were:

- Rotary valve vane sizing
- Rotary valve plugging
- Hopper level switch issues, and
- Hopper cracking due to wear and tear.

Figure 4 illustrates the number of facilities that experienced each challenge identified with the transfer of the lime powder from the storage silo to the slurry mix tank. There were 14 facilities analyzed, while reviewing Figure 4 it is important to remember that not all facilities had each component in the design.

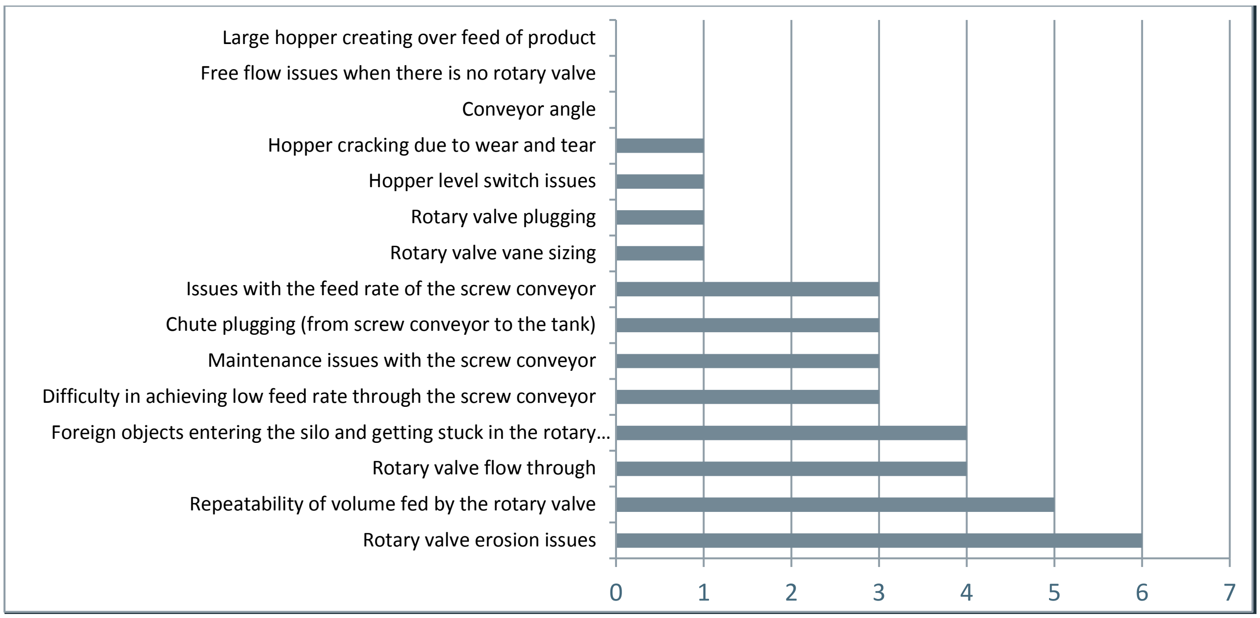

Figure 4 – Challenges associated with the transfer of lime from the storage silo to the slurry mix tank

Table 4 – Equipment and challenge matrix – lime transfer from silo to slurry mix tank

			Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Core equipment & Process Components	Rotary Valve, loss in weight hopper, screw conveyor, chute		X	-	-	X	-	-	-	-	-	-	X	-	X	X
	Rotary Valve, volumetric hopper, screw conveyor, chute		-	-	-	-	X[2]	X	-	-	-	-	-	-	-	-
	Rotary valve, screw conveyor, chute		-	-	X	-	-	-	-	-	-	-	-	-	-	-
	Hopper, screw conveyor, chute		-	X	-	-	-	-	-	-	X	-	-	-	-	-
	Rotary Valve, Chute		-	-	-	-	-	-	X	X	-	X	-	X	-	-
	Rotary valve	Does the system have a rotary valve?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
		Gate or knife valve to isolate silo?	No	Yes[1]	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
		Gate or knife valve closed during product offload?	-	Yes	No	No	No	No	-	No	-	Yes	No	No	Yes	No
		Size of rotary valve	8"	-	7"		10"	10"		6"	-	10"	8"	2 x 6"	8"	8"
		Clearance of rotary valve?		-		0.008" - 0.01"	0.003" - 0.005"	0.003" - 0.005"			-	0.004 - 0.007"				
		Material of rotary valve?	Cast iron body, carbon steel rotor	-	Steel	Carbon steel				Carbon Steel	-	Iron / Mild steel				
		Frequency of rotary valve change?	> 7 yrs	-	~1 yr			~ 5 yrs		~1 yr	N/A	> 3 yrs	0.5 / yr	~1 yr		~7.5 yrs
	Hopper	Does the system have a hopper?	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No	Yes	No[1]	Yes	Yes
		Vibrator on hopper?	Yes	No	-	Yes	No	No	-	-	Yes	-	No	-	Yes	No
		Vent on hopper	No	No		No	Yes	Yes			No		Yes		Yes	Yes
		Air injection into hopper	No	No	-	No	No	No	-	-	No	-	No	-	Yes	No
		Loss in weight hopper	Yes	-	-	Yes	-	-	-	-	-	-	Yes	-	Yes	Yes
		Volumetric hopper	-	Yes	-	-	Yes	Yes	-	-	Yes	-	-	-	-	-
		Level switch activated	-	Yes	-	-	No[2]	Yes	-	-	No[2]	-	-	-	-	-
		Loss in weight activated	Yes	-	-	Yes	-	-	-	-	-	-	Yes	-	Yes	Yes
	Screw conveyor, chute	Does the system have a screw conveyor?	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	No[1]	Yes	Yes
		Continuous screw conveyor	X	X	-	-	X	-	-	-	X	-	X	-	-	-
		Intermittent screw conveyor	-	-	X	X	-	X	-	-	-	-	-	-	X	X
		Type of screw conveyor	Conv. closed flight	Conv. closed flight	Conv. closed flight	Conv. closed flight	Conv. closed flight	Conv. closed flight	-	-	Conv. closed flight	-	Conv. closed flight	-	Conv. closed flight	Conv. closed flight

	Material of screw conveyor	Stainless steel	Carbon steel	Steel	Mild steel	Carbon Steel	Carbon Steel	-	-	Carbon Steel	-	304 SS	-	316 SS	
	Angle of screw conveyor	Flat	Flat	Flat	Flat	Flat	Flat	-	-	Flat	-	Flat	-	Flat	25 degrees up
	Sample location on screw conveyor	No	No	Yes	Yes	No	No	-	-	No	-	No	-	No	No
	Rodable screw conveyor	No	No	No	No	No	No	-	-	No	-	Yes	-	No	No
	Chute from screw conveyor?	No	Yes	Yes	Yes	Yes	Yes	-	-	No	-	Yes	-	Yes	Yes
	Chute material	-	Carbon steel	Carbon steel	Carbon steel	Fabric	Rubber	-	-	-	-	Teflon lined	-	Rubber	Rubber
	Air injection into chute?	-	No	No	No	No	No	-	-	-	-	No	-	Yes	No
Lime to tank	Batch lime into tank	X	X	-	X	X	X	-	-	X	-	X	X	X	X
	Continuous lime into tank	-	-	X	-	-	-	X	X	-	X	-	-	-	-
Tank venting	Is there a vent?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes[3]	Yes	Yes	Yes	Yes	No
	Vacuum on vent	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	-
	How is vacuum created?	Eductor	Eductor	Induced draft fan	Induced draft fan	Induced draft fan	Draft fan (not induced)	Induced draft fan	Induced draft fan (not in-line)	-	Natural circulation/ convection	Eductor	Eductor	Air driven venturi	-
	Wet scrubber on vet	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	-
	Vents outside	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	-
	Vent PMs	Cleaned monthly	Cleaned monthly							None		Yes Frequency unknown	Yes Frequency unknown	No	-
Slurry tank vent	Working	X	X		X	X	X	X	X		-	X	-		-
	Frequent plugging			X							-	-	-		-
	Not working									X	X	-	X		X
Lime dosed based on	Weight	X	-	-	X	-	-	-	-	-	-	-	-	-	X
	Volumetric	-	X	X	-	X	X	X	X	X	X	X	X	X	-
Mechanical component responsible for dosage	Rotary Valve	-	-	X	-	X	-	X	X	-	X	-	X	-	-
	Screw Conveyor	-	X	-	-	-	X	-	-	X	-	X	-	X	-
	Loss in weight hopper	X	-	-	X	-	-	-	-	-	-	-	-	-	X
Challenges	Rotary valve erosion issues	No	-	Yes	Yes	No	No	Yes	Yes	-	No	Yes	No	No	Yes
	Rotary valve flow through	No	-	No	No	Yes	No	Yes	Yes	-	No	No	Yes	No	No

	Rotary valve vane sizing	No	-	No	No	No	No	No	No	-	No	Yes[4]	No	No	No
	Repeatability of volume fed by the rotary valve (volumetric feeder)[5]	No	-	Yes	No	Yes	No	Yes	Yes	-	No	Yes[4]	No	No	No
	Rotary valve plugging	No	-	No	No	No	No	No	No	-	No	Yes[4]	No	No	No
	Foreign objects, such as gloves, entering the silo and getting stuck in the rotary valve	No	-	Yes	Yes	Yes	Yes	No	No	-	No	No	No	No	No
	Hopper level switch issues	Yes	-	No	No	-	No	-	-	No	-	No	-	-	No
	Free flow issues when there is no rotary valve	-	-	No	No	-	-	-	-	No	-	No	-	-	No
	Large hopper creating over feed of product	-	-	No	No	No	No	-	-	No	-	No	-	No	No
	Hopper cracking due to wear and tear	Yes	-	No	No	No	No	-	-	No	-	No	-	No	No
	Difficulty in achieving low feed rate through the screw conveyor	No	Yes	No	No	-	No	-	-	Yes	Yes[7]	No	-	No	No
	Maintenance issues with the screw conveyor– clean out product build up	No	No	No	No	Yes	No	-	-	Yes	Yes	No	-	No	No
	Chute plugging (from screw conveyor to the tank)	No	No	No	No	Yes	Yes	-	-	-[6]	-[6]	No	-	Yes	No
	Issues with the feed rate of the screw conveyor (e.g. overfeed / underfeed with manual variable control)	No	No	No	No	No	No	-	-	Yes	Yes	No	-	Yes	No
	Conveyor angle – do you have challenges that are attributed to the conveyor angle?	No	No	No	No	No	No	-	-	No	-	No	-	No	No

Notes:

1. There is no rotary valve, however there is a knife / gate valve before the downstream screw conveyor.
2. Volumetric hopper does not function as storage, what goes into the hopper goes out, rotary valve controls the dosing.
3. Vent is not active and does not have a filter - open tube.
4. There were issues with this prior to updates to the system including the installation of a loss in weight hopper.
5. This challenge is only relevant if the rotary valve is used as the volumetric feeder.
6. No chute.
7. This is no longer a challenge, but was a challenge with a previous system.
8. Batch: Full batch system, slurry is batched out of the slurry mix tank.
9. Continuous with recycle: Constant flowrate of lime slurry out of the slurry mix tank, the volume of slurry sent to the downstream reactor is controlled downstream of the mix tank with a control valve or a VFD on the lime feed pump.
10. Once through: Constant flowrate of makeup water to the slurry mix tank, constant flowrate of slurry out of the slurry mix tank and into the downstream reactor and varying amounts of lime powder being added to the slurry mix tank.

6.2 Analysis

All of the facilities analyzed experienced challenges with the transfer of the lime powder from the storage silo to the slurry mix tank. During the lime handling system workshops, as well as during previous work with the MgO handling system (WaterSMART, 2014), it was noted a fully redundant system from the storage silo onward would allow for preventative maintenance to be performed on one half of the system while the other half of the system was still operational. A fully redundant system would avoid any system shut downs. Although it is costly to design, build, and run a fully redundant system it is an effective way to prevent shutdowns and manage the challenges associated with the system downstream of the silo.

Proposed design guideline:

D7. A fully redundant system downstream of the silo will avoid system shutdowns when operational challenges occur throughout the system, and increase the efficiency of the system while it operates. Note that a fully redundant system may be cost and footprint prohibitive.

Throughout the transfer system from the silo to the slurry mix tank it is important lime powder does not escape the system and also that moisture does not enter the system. Lime dust can create challenges with dry lime buildup and excess dust in the work environment. External moisture entering the system can cause the lime powder to clump and subsequently plug the system. One facility noted that when the transfer equipment is located outside there are more issues with moisture entering the system.

Proposed design guidelines:

D8. Close and seal all open holes in the system where dust has the potential to enter the work environment or buildup on equipment.

D9. Ensure, if at all possible, that all system components downstream of the silo are located inside a building. If components must be located outside ensure that they are well sealed. This will avoid moisture ingress into the system and help avoid plugging.

The following sections discuss each potential lime powder transfer component separately; in Section 6 components are discussed and compared as a system.

6.2.1 Rotary valve

Twelve of the 14 facilities assessed had a rotary valve, four of these facilities had only rotary valves and no other powder transfer components.

As seen in Figure 4 the most common challenges reported with rotary valves were valve erosion, repeatability of volume fed by the rotary valve, rotary valve flow through, and foreign objects entering the silo and getting stuck in the rotary valve.

Six out of 14 facilities (43%) assessed reported rotary valve erosion issues at their facilities. Rotary valve erosion can cause many of the other challenges associated with the rotary valve such as valve flow through and inconsistency in the volume of lime powder being fed by the rotary valve.

Four of the facilities that experience rotary valve erosion challenges replaced the rotary valve frequently – two facilities replaced the valve every six months, one replaced it annually, the other facility replaced it as necessary. Ongoing scheduled preventative maintenance will not fix rotary valve erosion, but may mitigate challenges associated with valve erosion going unnoticed. See Section 11.0 for a proposed preventative maintenance schedule.

To facilitate preventative maintenance it is suggested a slide gate valve is installed upstream of the rotary valve. This slide gate valve allows for maintenance of all the lime transfer components between the lime storage silo and the slurry mix tank. As this valve may be quite crucial in times of lime transfer component failure it is suggested this valve be tested monthly.

Proposed design guideline:

D10. Install a slide gate valve immediately downstream of the storage silo to allow for isolation of the rotary valve and other lime transfer components.

Proposed operational and maintenance guideline:

O7. Test the slide gate valve located immediately downstream of the storage silo monthly.

Four of the six facilities that reported having erosional issues with the rotary valve used the rotary valve as the primary method of dosing lime powder to the slurry mix tank. If a rotary valve is the primary lime dosing component scheduled preventative maintenance is of the utmost importance and the risks associated with using only a rotary valve should be well understood; section 6.0 discusses the use of rotary valves for lime dosing.

6.2.2 Hopper

Nine out of 14 facilities (64%) assessed had either a loss in weight hopper or a volumetric hopper. Of these five were loss in weight hoppers, two were volumetric hoppers, and two did not operate as storage with volume or weight control. Volumetric hoppers typically use a level measurement device to control the hopper filling, loss in weight hoppers use a load cell to control the hopper filling.

There were very few challenges reported with hoppers. The challenges associated with hoppers include hopper level switch issues and hopper cracking due to wear and tear. These challenges were both experienced by one distinct facility.

One facility reported they had issues with the load cell on their loss in weight hopper, the load cell often became caked due to lime dust and moisture, and as a result the hopper had to be calibrated every six months. The same facility reported they had issues with the hopper cracking due to wear and tear.

Four facilities had vibrators on their hoppers and five facilities had vents on their hoppers. Due to the lack of challenges with the hoppers there is no data that suggests having a vibrator or a vent is necessary. However, in the second workshop it was determined the hopper should have a vent. The hopper should not have an active vent, if the hopper was under vacuum the lime powder would be sucked up into the vent and quickly clog the filter. Additionally, the hopper vent should not have a wet scrubber, a wet scrubber risks adding unwanted moisture into the hopper and plugging the hopper with lime.

Proposed design guideline:

D11. Include a vent on the hopper to prevent plugging and level control challenges in the hopper. The vent should be sized to accommodate the displaced air from the lime powder being fed into the hopper. The vent should have a dust sock.

Proposed operational and maintenance guideline:

O8. The vent on the hopper must be maintained in order to avoid dust in the workplace.

6.2.3 Screw conveyor

10 out of 14 facilities (71%) assessed had screw conveyors, all of the screw conveyors were conventional closed flight screw conveyors.

There were very few challenges associated with screw conveyors. The challenges that were associated with the screw conveyor were: issues with the feed rate of the screw conveyor and maintenance issues with the screw conveyor.

Proposed design guideline:

D12. Use a conventional closed flight screw conveyor for product transfer. A ribbon type screw conveyor should be avoided to prevent bypassing of powder through the conveyor and ingress of water vapor into the conveyor.

There was some discussion surrounding the angle at which the screw conveyor should be installed. The majority of screw conveyors were installed flat – nine out of ten (90%) of the screw conveyors were installed flat and one screw conveyor was installed at a 25 degree angle upwards. None of the facilities assessed experienced challenges with their screw conveyor that could be attributed to screw conveyor angle.

6.2.4 Chute to the slurry mix tank

Eight out of 14 facilities reported that they had a chute from the lime powder transfer mechanism to the slurry mix tank. Figure 5 shows a breakdown of the materials used to construct the chutes.

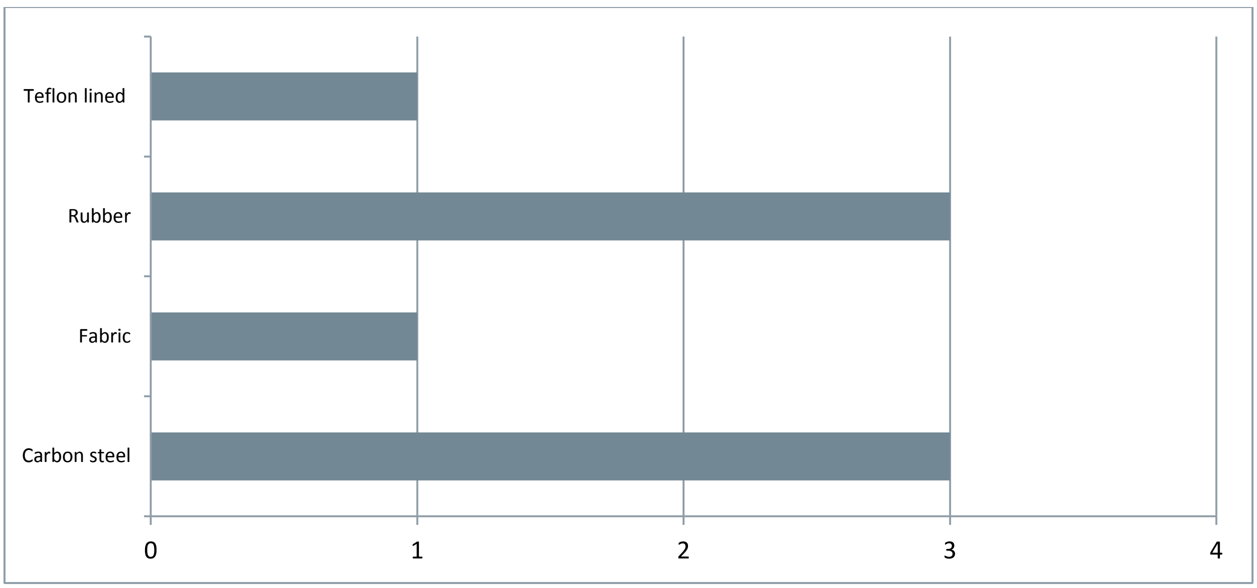

Figure 5 – Material of the chute to the slurry mix tank

The primary challenge associated with the chute was chute plugging (experienced by three facilities). There was no correlation between chute plugging and chute construction material. It was noted that having a properly functioning vent on the slurry mix tank reduces chute plugging. Further, many participants noted that regularly cleaning the chute mitigated issues with chute plugging. Two facilities that had experienced issues with chute plugging in the past noted they had changed the material used in their chute from carbon steel to rubber; the rubber is much easier to clean as it can be manipulated and the clumps of lime fall out.

Proposed design guidelines:

D13. Construct the chute from flexible material, such as an absorbent fabric, rubber, or neoprene to prevent accumulation of material on the walls and allow for easier cleanout. A rigid chute may increase vibration in the system and increase wear on the hopper.

D14. If the chute is constructed of a hard material include a y-lateral connection or some other form of cleanout connection.

Proposed operational and maintenance guideline:

O9. Implement a PM on the chute from the powder transfer components to the slurry mix tank to prevent plugging. Preventative maintenance should include a visual PM of the chute and the valves surrounding the chute during operator rounds.

7.0 Lime handling system dosing and concentration control

Components used to transfer the hydrated lime powder from the storage silo to the slurry mix tank are discussed individually in Section 5.0 of this report. One or several of the following components are used to transfer the lime powder from the silo to the slurry mix tank:

- Rotary valve
- Loss-in-weight hopper
- Volumetric hopper, and
- Screw conveyor.

These components can be used alone, or as a system of components to dose the lime powder to the storage silo. The components selected at each facility affect the operability of the facility as well as the accuracy of lime dosing.

There are three broader system methods to control lime slurry concentration:

- Once through method: The water flowrate into the slurry mix tank is constant, as is the slurry flowrate into the reactor. The amount of hydrated lime powder added to the slurry varies.
- Batching method: The hydrated lime powder and the water are mixed in the slurry mix tank in batched. Once the slurry is mixed the mixture is batch out of the mix tank to the reactor.
- Continuous with recycle method: The water flowrate into the slurry mix tank is constant and the hydrated lime powder flowrate into the tank is varied. The slurry flowrate into the downstream

reactor is varied and a portion of the slurry is recycled back to the slurry mix tank.

7.1 Results

Many operators indicated that managing the slurry concentration and dosing is not an exact science, they noted it is not generally necessary to manage the slurry concentration with a great degree of precision.

Table 5 summarizes the information collected on the lime dosing and slurry concentration control. Few operators indicated this was a major challenge in their system. The major challenges associated with lime dosing and slurry concentration control were:

- Achieving desired slurry concentration
- Measurement of slurry concentration, and
- Slurry metering.

Table 5 – Equipment and challenge matrix – Lime powder dosing and slurry concentration control

			Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Methods & Process	Slurry Concentration	Is there a slurry concentration goal?	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Not critical	No	No	No	
		What is the slurry concentration?	Min. conc.	Min. conc.	Min. conc.	Min. conc.	5% - 10%	5% - 10%	2.5 - 3% wt, 10 - 12% vol	3-5 v/v%	5 - 10 wt%	~ 5% vol (1-2% wt)	Min. conc.	Min. conc.	Min. conc.	1.1 g/cm3
		Measured in line	No	No	No	No	No	No	No	No	No	No	No	No	No	No
		Measured by grab samples	-	-	X	X	X	X	X	X	X	X	X	X	X	X
		In line measurement device	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Batch[1]		-	-	-	-	-	-	-	-	X	-	-	-	-	X
	Continuous with recycle[2]		-	-	-	-	X	X	X	-	-	-	-	-	-	X
	Once through[3]		X	X	X	X	-	-	-	X	-	X	X	X	X	-
	Lime dosed based on	Weight	X	-	-	X	-	-	-	-	-	-	-	-	-	X
		Volumetric	-	X	X	-	X	X	X	X	X	X	X	X	X	-
	Mechanical component responsible for dosage	Rotary Valve	-	-	X	-	X	-	X	X	-	X	-	X	-	-
		Screw Conveyor	-	X	-	-	-	X	-	-	X	-	X	-	X	-
		Loss in weight hopper	X	-	-	X	-	-	-	-	-	-	-	-	-	X
	Control basis	Makeup water to slurry tank	-	-	-	-	X	X	-	-	-	-	-	-	-	-
		Water flow to reactor	X	X	-	X	-	-	-	-	-	-	X	X	-	-
		Hardness of effluent	-	-	X	-	X	X	-	X	-	-	-	-	-	X
		Alkalinity of effluent	-	-	X	X	-	-	-	-	-	-	-	-	-	-
		pH of reactor	-	-	-	-	-	-	-	X	X	X	X	X	X	-
		pH of effluent	-	-	X	X	X	X	X	-	-	-	-	-	-	-
Challenges	Achieving desired slurry concentration[4]		-	-	-	-	Yes	No	No	No	No	-	No	No	Yes	No
	Measurement of slurry concentration[4]		-	-	-	-	No	No	No	No	No	-	No	No	No	-
	Slurry metering[4]		-	-	-	-	No	No	No	No	-	No	-	-	-	No

Notes:

1. Batch: Full batch system, slurry is batched out of the slurry mix tank.
2. Continuous with recycle: Constant flowrate of lime slurry out of the slurry mix tank, the volume of slurry sent to the downstream reactor is controlled downstream of the mix tank with a control valve or a VFD on the lime feed pump.
3. Once through: Constant flowrate of makeup water to the slurry mix tank, constant flowrate of slurry out of the slurry mix tank and into the downstream reactor and varying amounts of lime powder being added to the slurry mix tank.
4. Where "-" is entered in relation to the challenge it is indicative that the operator did not have this challenge because they do not try to control that portion of the system.

7.2 Analysis

7.2.1 Lime dosing and transfer system

The hydrated lime powder can be transferred from the storage silo to the slurry mix tank either volumetrically or on a mass basis. If the powder is transferred volumetrically it can be transferred by a rotary valve, a screw conveyor, a volumetric hopper in conjunction with a screw conveyor or a combination of these components. If the powder is transferred on a mass basis is it controlled by a loss in weight hopper. Figure 6 illustrates the lime powder transfer components used at the facilities assessed in this work.

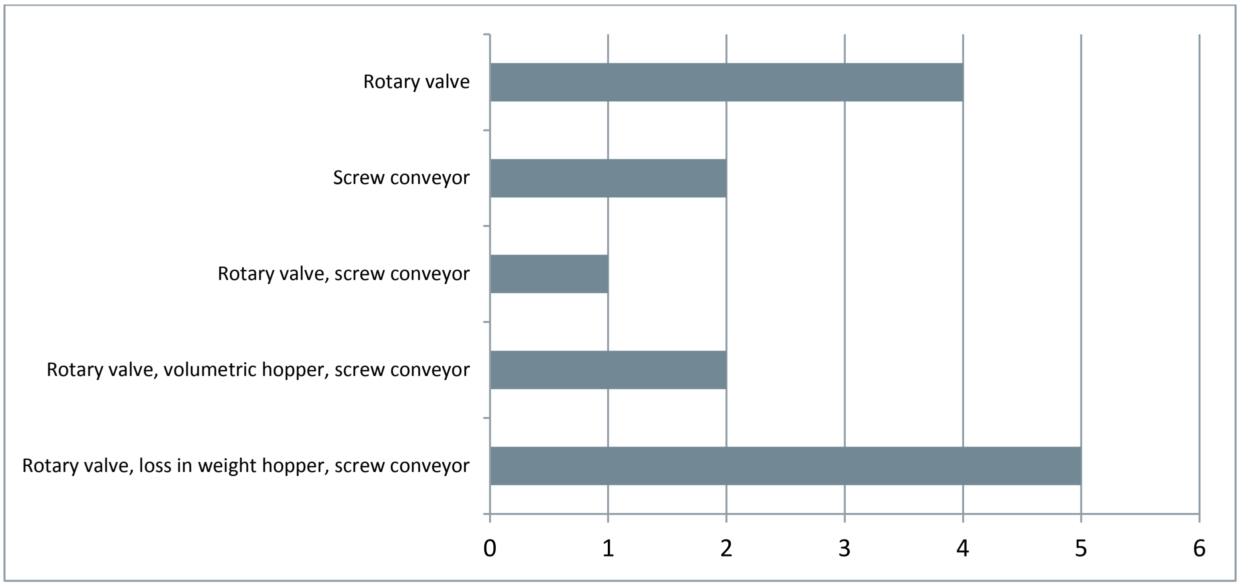

Figure 6 – Lime powder transfer components used

Figure 7 illustrates the mechanical component that is responsible for dosing the lime powder at the facilities assessed in this work. It is important to note while Figure 7 represents the component dosing the lime at each facility, it does not necessarily indicate that this component is a standalone component.

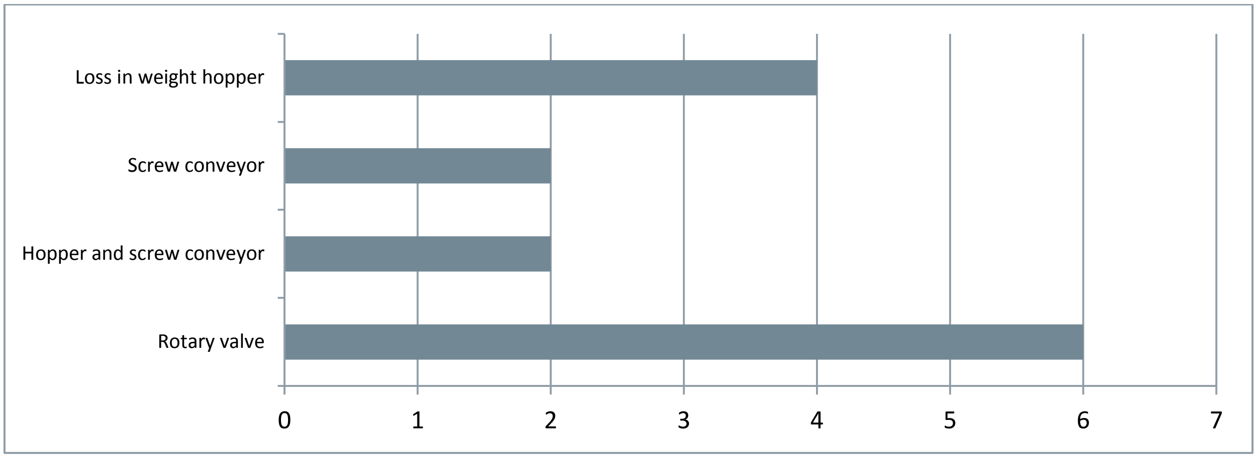

Figure 7 – Mechanical component responsible for dosing lime powder

Four facilities noted rotary valve flow through was an issue – all of these systems used the rotary valve as the main lime dosing control mechanism to the slurry mix tank. Additionally, four of the six facilities that use the rotary valve for lime powder dosing control noted repeatability of the volume of lime fed by the rotary valve was an issue.

Two of the facilities that currently use the rotary valve as lime powder volume control are in the process of changing their dosing systems. One facility noted they are changing their control philosophy so a volumetric hopper and a screw conveyor control the dosing. The owner of this facility also operates a system that currently uses a volumetric hopper and a screw conveyor to dose the lime powder; they noted this system had better control and less operational issues.

The other facility noted they will be changing to a loss in weight system with a screw conveyor. The owner of this facility has another facility that uses a loss in weight hopper and a screw conveyor, they noted this system was much more accurate and presented fewer operational challenges.

Proposed design guideline:

D15. Caution should be taken if a rotary valve is used as the sole method of lime powder volume control. See Table 6 for a comparison of different lime powder volume control components.

Two of the facilities that use the rotary valve as the primary dosing control change the valve out frequently to mitigate valve erosion issues, one facility changes the valve every six months and one changes it annually.

Proposed operation and maintenance guideline:

O10. If a rotary valve is used at the sole method of lime powder volume control it may need to be changed out frequently due to valve erosion issues, this should be reflected in the PM schedule.

Many facilities that do not use the rotary valve for lime powder dosing noted if there was valve flow through they likely wouldn't notice, because the rotary valve is not a central control mechanism for lime powder dosing.

Two facilities out of 14 assessed (14%) used a screw conveyor for lime dosing without the use of a rotary valve or a loss in weight or volumetric hopper. Both of these facilities noted they had challenges achieving low flowrate through the screw conveyor; these were the only two facilities which identified this as a challenge. A screw conveyor is prone to product flow through if the lime powder is over aerated in the silo.

Proposed design guideline:

D16. A screw conveyor should not be used as the sole mechanism for lime dosing without another lime transfer component. Screw conveyors are prone to lime flow through if there is no upstream lime control mechanism between the silo and the screw conveyor.

Nine of the 14 facilities (64%) assessed had a hopper at their facility, five of these hoppers were loss in weight hoppers, two were volumetric hoppers, and two did not operate as storage with volume or weight control. Volumetric hoppers use a level measurement device to fill and loss in weight hoppers use a load cell. See Section 6.2.2 for a discussion surrounding the hoppers themselves.

There were few reported challenges with the hoppers at the facilities assessed; when hoppers are used they add accuracy and control to lime dosing systems. Load cells or level control devices have been used to measure the flow into the hopper, the decision to use a loss in weight hopper or a volumetric hopper depends on the desired accuracy and the availability of funds (National Lime Association, 1995). Table 6 offers a comparison between loss in weight and volumetric hoppers.

Proposed design guideline:

D17. It is recommended that a hopper is included as a component in the powder transfer and lime dosing system. Table 6 offers a comparison between lime dosing strategies.

Table 6 – Comparison of lime dosing strategies

Component responsible for lime powder dosing	Advantages	Disadvantages
Only rotary valve	• Fewer components to maintain • Fewer components to have issues with • Less up front capital cost	• System may be prone to valve erosion and challenges associated with valve erosion • Valve may need to be replaced frequently • Less accurate volumetric control of lime dosing
Only screw conveyor	• Fewer components to maintain • Less up front capital cost	• System is prone to flow through • Less accurate volumetric control of lime dosing
Loss in weight hopper[1]	• More accurate lime dosing control (±1% by weight) (National Lime Association, 1995) • Newer loss-in-weight hoppers have a user friendly interface	• More expensive • Area must remain dust free, and/or device cleaned regularly (more maintenance required than a volumetric hopper) • Older models are difficult to operate
Volumetric hopper[1]	• Less expensive than a loss in weight hopper • Less maintenance required than with a loss-in-weight hopper	• Less accurate lime dosing control than with a loss in weight hopper(typical error of 3 to 7% by weight) (National Lime Association, 1995) • Plugging of level switches may create inconsistent process control

Notes:

1. Hopper systems generally have a screw conveyor after the hopper.

7.2.2 Slurry dosing and control system

Figure 8 illustrates the methods of lime slurry dosing control. One facility operates a system that is a batch system and also has recycle; therefore the total number counted is 15, whereas there were 14 facilities assessed.

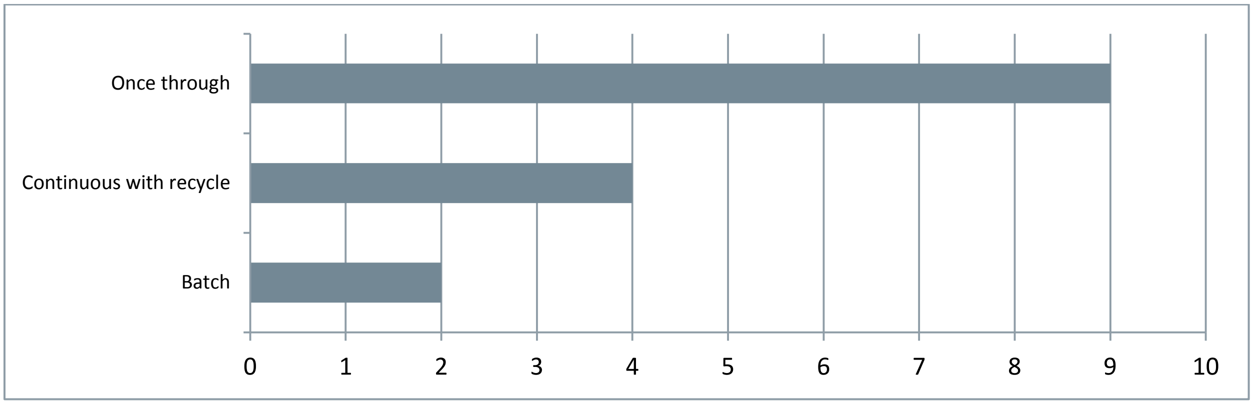

Figure 8 – Method of lime slurry control

Of the facilities assessed in this work, only two noted challenges with lime slurry dosing and control, these two facilities noted challenges with achieving desired slurry concentration. One facility noted the challenge was not substantial enough to require addressing while the other noted they would be changing from a rotary valve controlled lime dosing to a hopper and screw conveyor controlled system. Further discussion on this can be found in Section 6.2.1.

No facilities assessed had in line slurry measurement devices, however 12 out of 14 facilities (86%) use grab samples to verify slurry concentration on a regular basis.

Proposed operation and maintenance guideline:

O11. Sample slurry prior to the reactor at a minimum of once per shift to ensure there is lime present in the slurry feed.

Other challenges thought to potentially correlate to dosing and control strategy were:

- Plugging of slurry transfer lines, and
- Settling of solids in the bottom of the tank.

For discussion surrounding these challenges see Section 8.0 (Slurry mix tank) and Section 9.0 (Slurry transfer lines and feed pump).

8.0 Slurry mix tank

Lime powder and water are added to the slurry mix tank where an electronically driven agitator mixes them to produce lime slurry. The main components of the slurry mix tank are the tank baffles, the agitator, the tank venting system and the manhole(s). To ensure proper mixing of the slurry the baffles, agitator, and tank must be properly designed and sized. The venting system is crucial to preventing formation of solids above the liquid level in the tank and to preventing plugging upstream of the tank.

8.1 Results

The lime slurry mix tank created challenges in all of the facilities assessed. Table 7 summarizes the data collected regarding the lime slurry mix tanks; the core equipment and process components and challenges experienced at each facility are shown. The major challenges in relation to the lime slurry mix tank were:

- Settling of solids in the bottom of the tank
- Splashing from the mixer or the water inlet
- Scaling in the slurry mix tank
- Solids formation due to slashing, dust, and moisture
- Dust control
- Vent plugging, and
- Level measurement and control issues.

Additional challenges were:

- Foaming in the tank
- Limited capacity to conduct preventative maintenance
- Solids formation due to dust and moisture
- Achieving desired slurry concentration
- Settling in the corners of the tank, and
- Tank corrosion.

Figure 9 illustrates the number of facilities that experienced each challenge identified with the slurry mix tank; the figure shows the number of facilities that experienced each challenge out of a total of 14 facilities that were analyzed.

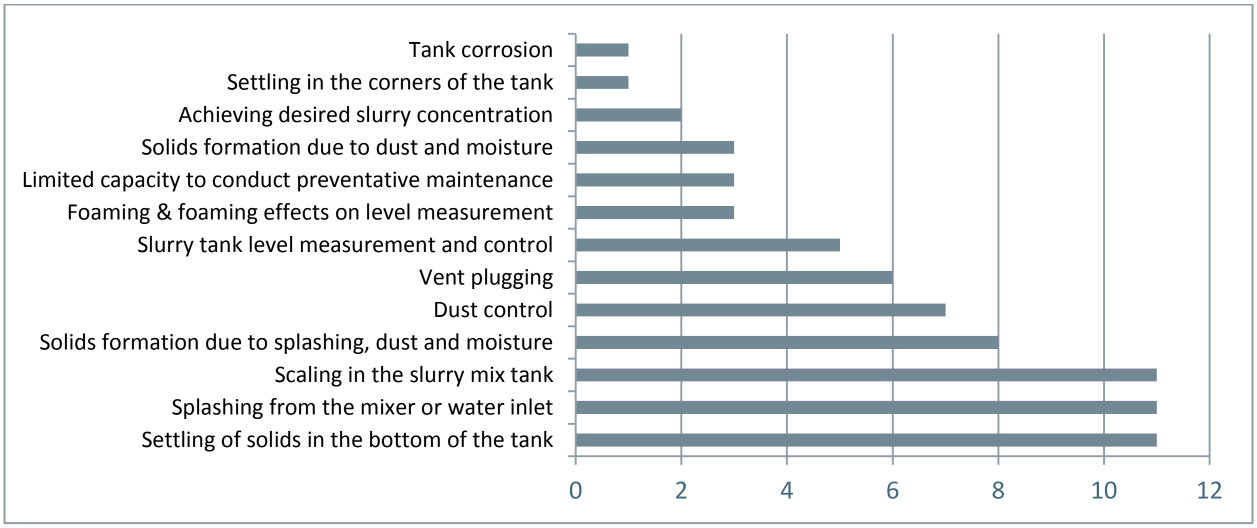

Figure 9 – Challenges associated with the slurry mix tank

Table 7 – Equipment and challenge matrix – slurry mix tank

			Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Core equipment & Process Components	Location of Lime inlet to tank	Top centre	-	-	-	-	-	-	-	-	X	-	-	-	-	-
		Top to the side	X	X	-	-	-	X	X	X	-	X	-	-	-	X
		Top	-	-	X	X	X	-	-	-	-	-	X	X	X	-
	Lime and MgO are mixed in the same tank		No	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes
	Location of water inlet to tank	Top	X	X	-	X	X	X	-	-	-	-	-	-	X	X
		Side above NLL	-	-	-	-	-	-	-	-	X	X	X	X	-	-
		Side below NLL	-	-	X	-	-	-	X	X	-	-	-	-	-	-
		Bottom	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Distance between the water inlet and the lime inlet? (m)				1	1	1.7	2.3	1.8	~1.5	1.314	~1	1.053		~1	2
	Agitator	RPM			370	100	218	170		100	1725	350	350	350	87	226
		Horsepower	1		3	3	10	10	1.5	2	1.5	1	2	1	5	3
		Number of impellers	1	1	3	1	2	2	4	4	2	1 impeller, 3 blades	1	1	2	3
		Size of impellers (mm)	304.8	304.8	419.1	813		685.8		304.8	383.54	384	355.6	383.54	Bottom: 635 Top: 762	546.1
		Impeller to tank diameter ratio	0.22	0.22	0.23	0.33		0.17		0.17	0.22	0.21	0.20	0.21	0.32	0.22
		Type			Maxflo	Pitched turbine blade	Sloped blade	Angled Blades (4 blades)		Pitched blade (45 degrees)	Axial flow impeller	A 310	Marine	Wedge shaped lightnin	Dyamix - Model GMX3-21-5	
		Direction of slurry mixing	Down	Down	Down	Down						Down	Down	Down	Top - towards bottom Bottom - towards side	Down
		Distance from NLL to impeller (mm)	478	478	500		1524 2946			500-750	Batch op.	1100				490
		Inclined agitator	-	-	-	-	-	-		X	X	-	X	-	-	-
		Vertical agitator	X	X	X	X	X	X		-	-	X	-	-	X	X
	Baffles	Are there baffles?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes
	Vent on slurry tank	Is there a vent?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes[3]	Yes	Yes	Yes	Yes	No
		Type of vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum	Vacuum vent	Open pipe	Open pipe	Vacuum vent	Vacuum vent	Vacuum vent	-

								vent							
	Capacity of vent (m^3/hr)	167	381		337				168	-		220	170	251	-
	How is vacuum created?	Eductor	Eductor	Induced draft fan	Induced draft fan	Induced draft fan	Draft fan (NOT induced)	Induced draft fan	Induced draft (not in-line)	-	Natural circulation/convection	Eductor	Eductor	Air driven venturi	-
	Scrubber on vent	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	-
	Type of scrubber on vent	Wet	Wet	Dry	Wet	Wet	Wet	-	Wet	-	Wet	Wet	-	Wet	-
	DP meter on scrubber	No	No	Yes[1]	No	No	No	-	No	-	No	No	-	No	-
	Baffles in vent			No	Yes		Yes	-	Yes	-	No	No	No	No	-
	Baffles in vent are angled			-	Yes			-	Yes	-	-	-	-	-	-
	Vents outside	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	Yes	Yes	Yes	Yes	-
	PMs	Yes	Yes	Yes	Yes					-		Yes	Yes		-
Tank	Tank diameter (mm)	1370	1370	1830	2440	3960	3960	1800	1800	1720	1803	1800	1829	2410	2440
	NLL in tank	0.73	0.73	65%	1.46	2.2	2.5	1.55	1.5	Batch op.	1.3	1.4	1.0	1.3	2.1
	Manhole on top	-	-	-	X	-	-	X	-	X	X	X	X	-	X
	Manhole on side	X	X	X	X	X	X	X	X	-	X	X	X	X	-
	Tank material			Fiberglass	Steel	Fiberglass	Fiberglass			Carbon Steel	Carbon steel				
	Is the tank lined?	No	No	No		No	No		Devchem coating	No	Epoxy				
Level Measurement	Accurate?	Yes	Yes	Yes	Yes	No[2]	No[2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Guided waver radar	X	X	-	-	-	-	-	X	-	-	-	-	-	-
	Radar	-	-	-	-	-	-	-	-	-	-	-	-	X	-
	Differential Pressure	-	-	-	-	-	-	-	-	-	-	-	X	-	-
	Ultrasonic	-	-	-	-	X	X	X	X	X	-	X	-	-	X
	Bubble Tube	-	-	X	X	-	-	-	-	-	X	-	-	-	-
	Redundant devices	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	-	No	No	Yes	No
	PMs	Yes	Yes	Yes	Yes	Yes	Yes				Yes	Yes	Yes		
Water Quality	Temperature (°C)	35 - 45	35 - 45	10 - 20	< 40	40	40	20 - 25	10 - 20	45	20 - 40	< 40	< 40	5 - 40	5 - 15
	pH	9.6 - 10.2	9.8 - 10.2	9 - 10	9.3 - 9.5	9.0 - 9.5	9.0 - 9.5	9.4	8	8 - 8.7	7.8	9.9	9.9		7.8
	TOC (ppm)			150 - 200	100 - 200	170		3	5 - 15	<150	127				
	Conductivity (µS/cm)	<10,000	<10,000	20		11,000		12,700	12,000 - 14,500	12,000 - 15,000	150	8,000 - 10,000	7,000 - 11,000		450
	Total Alkalinity (as mg $CaCO_3$)	481	481	80 - 100	60 - 80	550 - 750		783	520 - 590	Not measur	88	625 - 700	350 - 550		240

										ed					
	Bicarbonate Alkalinity (as mg CaCO3)	308	308	10	10			387	640 - 720	Not measured	88	200 - 300	75 - 175		290
	Hardness (as mg CaCO3)	0.5	0.5	0 - 300	< 0.3	0.2 - 1.0		4.9	< 10	<0.075	<0.25	< 0.2	< 0.5		210
Solids buildup	How often must solids buildup be removed from the tank wall?	Weekly	Weekly	~ 6 months	> 1.5 years	6 - 12 months	~12 months	4 weeks	~12 weeks	8 weeks	~14 weeks	1/yr	2/yr	2 - 3 months	Never
PMs	Water Flush	-	-			None	X							X	-
	Acid Flush	X	X			-	X			X	X	X	X	-	-
	Frequency	2 weeks	2 weeks			-	Annually	Monthly	10 - 12 weeks	8 weeks	Quarterly	8 months	8 months	2 - 3 months	-
Are recirc lines used?		-	-	-	-	Yes	Yes	Yes	No	Yes	Exist (aren't used)	Exist (aren't used)	Exist (aren't used)	No	Yes
Lime batched into tank		X	X	-	X	X	X	-	-	X	-	X	X	X	X
Continuous lime into tank		-	-	X	-	-	-	X	X	-	X	-	-	-	-
Slurry batched out of tank		No	No	No	No	No	No	No	No	Yes	No	No	No	No	Yes
Continuous with recycle		-	-	-	-	X	X	-	-	-	-	-	-	-	-
Continuous with VFD		-	-	-	-	-	-	-	-	-	-	-	-	-	-
Batched with recycle		-	-	-	-	-	-	-	-	X	-	-	-	-	X
Once through system		X	X	X	X	-	-	X	X	-	X	X	X	X	-
Slurry	There is a slurry concentration target	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes
	What is the slurry concentration	-	-	-	-	5 - 10%	5 - 10%	2.5 - 3% wt, 10 - 12% vol	3-5 v/v%	5 - 10 wt%	~5% vol (1-2% wt)	-	-	-	10% wt
	Slurry residence time (mins)		7.8	30	30	72	240	12 - 15	20 - 30	18	~ 20			30 - 40	360
	Is slurry aid added	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No
	Where is the slurry aid inlet	-	-	-	-	Slurry tank	-	-	-	-	-	-	-	-	-
Challenges	Overall system moisture control challenges	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes
	Vent plugging	Yes	Yes	Yes	No	No	No	Yes	No	No[3]	No	No	Yes	Yes	No[3]
	Settling of solids in the bottom of the tank	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
	Tank corrosion	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No
	Slurry tank level measurement and control	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
	Foaming & foaming effects on level	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	No	No

measurement															
Scaling in the slurry mix tank		Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Limited capacity to conduct preventative maintenance / lack of visibility into the tank		No	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No
Splashing from the mixer or water inlet		Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
Settling in the corners of the tank		No	No	No	No	No	No	No	No	No	No	No	No	No	Yes
Solids	Unknown cause			-	-	-	-	-	-	-	-	-	-	-	-
	Due to splashing	X		-	-	X	X	X	X	X	X	-	-	X	-
	Due to dust & moisture	X		-	-	X	X	X	X	X	X	X	X	X	X
Dust control		Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	No	No	Yes	No
Achieving desired slurry concentration		-[4]	-[4]	-[4]	-[4]	Yes	No	No	No	No	-[4]	No	No	Yes	No

Notes:

1. DP meter on vent to detect plugging, no scrubber installed.
2. Due to foaming and solids buildup on transmitters.
3. Vent is not active and does not have a filter - open tube.
4. No slurry concentration target.
5. Batch: Full batch system, slurry is batched out of the slurry mix tank.
6. Continuous with recycle: Constant flowrate of lime slurry out of the slurry mix tank, the volume of slurry sent to the downstream reactor is controlled downstream of the mix tank with a control valve or a VFD on the lime feed pump.
7. Once through: Constant flowrate of makeup water to the slurry mix tank, constant flowrate of slurry out of the slurry mix tank and into the downstream reactor and varying amounts of lime powder being added to the slurry mix tank.

8.2 Analysis

Most challenges associated with the slurry mix tank were caused by improper mixing, improper vent design, or poor vent maintenance. Improper mixing can be caused by ineffective tank design parameters such as tank sizing, baffle design, agitator type and size, and even the slurry pump suction placement. Poor venting can be caused by improper vent design or poor vent maintenance. The slurry tank vent is a vital component as it affects the upstream slurry handling system; a properly functioning slurry tank vent prevents moisture from travelling from the tank to the dry powder handling portion of the system.

While various design components are discussed in this report, and correlations made between these components and various challenges, it is likely no single design component or operational difference is responsible for any given challenge. For example, at a facility missing both tank baffles and venting it is likely both of these missing components are contributing to an issue.

Therefore, the following analysis and proposed guidelines aim to provide the greatest level of detail possible that can be applied to design, operation, and maintain the slurry mix tank based on data analysis in addition to anecdotal experience and technical knowledge.

8.2.1 Tank sizing and material

The capacity of slurry mix tanks at the facilities assessed varied from 2.0 m^3 to 45.1 m^3. Typically the tank size and configuration is dictated by space availability and process decisions – for example if the lime is batched into the reactor or not. It was not possible to draw conclusions for the ideal tank size or configuration based on the information collected in this assessment.

Tank size has an impact on the residence time of the lime slurry from the initial mixing until it reaches the downstream reactor. The slurry residence times at the facilities assessed ranged from seven minutes to six hours. As the lime has already been slaked residence time is not a crucial variable for system efficiency; facilities with higher slurry residence time did not appear to have increased challenges with their slurry mix tanks or with the downstream pumps or piping.

The slurry mix tank should be sized specifically for each process, some of the variables that should be considered in the sizing of the tank are: continuous or batch process, the desired slurry concentration, the desired retention time, and the required injection rate to the downstream reactor. These variables should also be considered while modeling the slurry mix tank to ensure proper mixing.

Proposed design guideline:

D18. Slurry mixing modelling should be undertaken to ensure adequate mixing of the slurry in the tank, considering all appropriate variables related to the tank geometry and baffles, and water temperature. The mixer manufacturer can undertake modelling on behalf of the designer. See proposed design guideline 28.

Six facilities reported the material of the slurry mix tank – three facilities had carbon steel mix tanks and three facilities had fiberglass mix tanks. One facility noted corrosion was an issue in their mix tank; this tank is 25 years old and has corrosion on the top of the tank. One facility noted their fiberglass tank was challenging to clean as high pressure water could not be used. None of the facilities were unsatisfied with the material of their slurry mix tank.

8.2.2 Slurry mix tank venting and dust control

The slurry mix tank vent and dust control system is crucial, not only to the operation of the slurry mix tank, but also to the operability of the upstream components. Without a properly functioning vent on the slurry mix tank the vapor from the makeup water is not properly expelled from the system and thus has the potential to become entrained in process equipment upstream of the slurry mix tank. The major challenges associated with the slurry mix tank venting system are moisture control issues upstream of the slurry mix tank causing caking and plugging, moisture and dust issues in the slurry mix tank causing solids formation on the tank walls, and slurry mix tank vent plugging.

The majority of the facilities assessed had vents on their slurry mix tanks. 13 out of 14 facilities had some form of vent on the slurry mix tank. One facility did not have a vent, two facilities had an open pipe vent, and 11 facilities had a vacuum vent.

Eight facilities (57%) reported issues with moisture control in the overall lime handling system. Three of these facilities either did not have a vent or did not have a vacuum on the vent system. Of the facilities that reported having a vacuum on the vent six (55%) reported having moisture control issues upstream of the slurry mix tank.

Proposed design guideline:

D19. Include a vent system with a vacuum on the slurry mix tank to mitigate dust issues and to control moisture upstream of the slurry mix tank. See guidelines 20 to 25 for tank vent system design. Maintenance is essential to ensure ongoing venting, see operational and maintenance guidelines 12 to 14.

The vacuum on the slurry mix tank vent can be created by an off-line fan, through eduction, or by an in-line fan. Of the facilities that had a vacuum on the slurry mix tank vent at least five created the vacuum using an off-line fan such as a venturi. During the one-on-one interviews several facilities reported having greater success with an eduction fan or a venturi, it was noted an in-line fan tends to get plugged with moisture and solids that are pulled from the slurry mix tank.

Proposed design guideline:

D20. The slurry mix tank vent should be under negative pressure, pulling a slight vacuum on the slurry mix tank. In order to create the vacuum, facilities have had greater success with educator fans, such as a venturi, than with an in-line induction draft fan. Many participants noted that in-line fans tend to get plugged.

The capacities of the slurry mix tank vents ranged from 168 m^3/hr to 381 m^3/hr; the vent capacity did not correlate strongly with tank size, nor did change in vent size correlate with an increase or decrease in challenges such as vent plugging challenges or challenges with moisture in the mix tank. The vent should be sized based on mix tank size and the water temperature in the tank should be considered when the vent is sized.

Proposed design guideline:

D21. Design the slurry mix tank vent as required, to handle the design water temperatures and tank sizing. Consider designing the vent for water temperatures greater than expected design temperatures to ensure the vent can still operate with a change in source water.

Six facilities reported challenges with plugging of the slurry mix tank vent. Four of these facilities noted that they had recently updated, or were currently updating, their vent. The updates to the vents included:

- Adding an orifice plate to ensure that the vent was not pulling moisture from the tank
- Removed in-line fan and replaced it with an off-line induction fan, changed vent baffles from 90° to 45°
- Adding a wet scrubber to the vent, and
- Adding a venturi.

Nine of the 14 facilities (64%) had wet scrubbers on the slurry mix tank vent. Three of the nine facilities (33%) with a wet scrubber on the slurry mix tank vent reported challenges with vent plugging; three out of five facilities (60%) without a wet scrubber reported vent plugging as a challenge. Many participants noted having a proper scrubber on the slurry mix tank has helped deal with moisture issues in the system – three participants noted that they would be adding a scrubber or updating their scrubber design in order to deal with moisture issues in the system.

Proposed design guidelines:

D22. The slurry mix tank vent system should include a wet scrubber with baffles. It should operate under negative pressure and vent outside.

D23. The slurry mix tank vent should have baffles. The baffles should be at 45° from the wall and should be staggered (alternating either side).

Dust is created when the hydrated lime powder is dropped into the tank. Dust issues in the slurry mix tank were reported by half of the facilities assessed (seven out of 14). Five of the facilities that reported dust issues also reported issues with solid buildup on the walls of the tank due to dust and moisture in the air (this challenge was reported by 11 facilities). Having a slight vacuum over the vent and having a wet scrubber on the vent may help decrease dust issues.

The reported temperature of the makeup water at the facilities that have vent plugging varied from as low as 5°C to as high as 45°C. Due to the large variety in water temperature no direct correlation can be made between water temperature and vent plugging. However, during one-on-one interviews three participants noted high water temperature leads to challenges within the slurry system. There was general consensus during workshops that cooler water temperature added to system operability (see proposed design guideline 57).

Decreasing water temperature was also noted to be another way to mitigate moisture issues throughout the system. However, to highlight the importance of a properly designed vent on the slurry mix tank one participant noted having a proper vent on the slurry mix tank was a much more cost effective way of dealing with moisture than adding additional heat exchangers to cool that mixing water.

The vent must be sized to create a balance of air into the slurry mix tank versus air vented out of the tank. To ensure a balance, especially during changes within what can be a dynamic system, the vent fan can be run on either a variable frequency drive (VFD), or a butterfly valve can be installed on the outlet of the vent fan. Adjustment of either device will ensure the appropriate airflow balance is achieved. Vent operation is particularly important if a butterfly valve is used. If the valve is wide open there will be no vacuum; if the valve is not open enough it will create too much vacuum pressure and lead to plugging.

Proposed design guidelines:

D24. Locate the slurry mix tank vent as far away as practical from the lime powder inlet. If the vent and the inlet are in close proximity the vent will suck up the powder and plugging will occur more quickly.

D25. If vent plugging is an issue consider including a variable frequency drive (VFD) or a butterfly valve on the vent to allow for manual or remote changes to the vent air intake to prevent plugging (see operational and maintenance guideline 14).

Six facilities reported having regular PMs on the slurry mix tank vent, six other facilities were unsure if PMs were in place for the slurry mix tank vent. There was no evidence among the facilities analyzed that slurry tank vent PMs decreased vent plugging or overall moisture control challenges in the system. However, participants agreed that there is value in ensure that the slurry mix tank vent is operating, and that it continues to operate. Having scheduled PMs on the vent will decrease the chances that the vent will plug and fail. It is suggested that the slurry mix tank vent should be visually inspected monthly. Furthermore, a differential pressure meter over the vent can be used as a tool to monitor the need for maintenance; an increase in differential pressure will indicate that vent cleaning is necessary.

Proposed operation and maintenance guidelines:

O12. Ensure that the slurry mix tank vent is functioning at all times during operation to mitigate dust issues, control moisture upstream of the slurry mix tank, and minimize humidity within the slurry tank vapor space.

O13. The slurry mix tank vent scrubber should be visually inspected monthly. A differential pressure meter across the scrubber could also be used to indicate when full cleanings are required but should not be used as the sole means of determining maintenance requirements.

O14. Use the VFD or butterfly valve on the slurry mix tank vent to adjust the air intake as necessary to avoid plugging.

8.2.3 Slurry tank baffles

Eleven out of 14 facilities (79%) assessed had baffles in their slurry mix tank. One facility had removed the baffles from their slurry mix tank, and had subsequently added them back in, this facility noted the reinstallation of the baffles had decreased settling in the bottom of the slurry mix tank. One additional facility noted they would be adding baffles into the tank to increase mixing efficiency and decrease settling in the bottom of the slurry mix tank.

Baffles are generally included in slurry mix tanks in order to prevent vortex formation caused by agitation. Literature suggests that tanks should be fitted with four baffles set 90° apart or three baffles set at 120° to promote effective mixing. Additionally, baffles should be no higher than the high liquid level. It is further suggested that baffles should be 1/12 of the tank diameter, perpendicular to the tank wall, and have an off wall space of 1/24 of the tank diameter (ZMI Chemical Processing Group).

Proposed design guidelines:

D26. Include four baffles set 90° apart or three baffles set at 120° to promote effective mixing in the slurry mix tank. Baffles should be no higher than the high liquid level.

D27. Baffles should be 1/12 of the tank diameter, perpendicular to the tank wall, and have an off wall space of 1/24 of the tank diameter.

Proposed operation and maintenance guideline:

O15. Consult your equipment supplier prior to making changes to critical slurry tank mixing equipment. Making changes without consultation can create greater system challenges instead of improvements. Particularly, do not remove baffles from the slurry tank.

8.2.4 Slurry tank agitator and mixing

No facilities assessed expressed challenges with the slurry tank agitators themselves, however many of the reported challenges can be related to slurry tank agitators. The challenges associated with the slurry tank agitator are: settling of solids in the bottom of the tank, experienced by 11 of 14 facilities (79%), and splashing from the mixer or water inlet, experienced by 11 of 14 facilities (79%).

Proper agitation ensures effective slurry mixing and stabilization. Agitators must be designed to maintain the impurities and precipitated salts, as well as the lime, in suspension. Proper agitator design should consider the tank sizing and shape, agitator impeller rotation speed, and the agitator horsepower. Modelling, by the facility owner or an agitator supplier, should be done to determine the optimal agitator impeller design as a function of tank size and shape, the specific gravity of the lime mixture, and the settling rate of the suspended solids.

Proposed design guideline:

D28. Modeling should be undertaken to determine the optimal agitator impeller design as a function of tank size and shape, the specific gravity of the lime mixture, and the settling rate of the suspended solids.

The data collected in this work does not show a correlation between slurry tank challenges and agitator speed or horsepower. Literature indicates that propeller or axial flow turbine agitator blades are often used on smaller tanks and should rotate at approximately 350 rpm. Whereas turbine type impellers are often used on larger tanks and should turn at speeds of 100 rpm or less (Beals, 1976 and American Water Works Association and American Society of Civil Engineers, 2005). About 1.5 to 1 hp per 3,785 L (1,000 gal) of tank capacity is required for cylindrical tanks of less than 11,400 L (3,000 gal) capacity and slurry concentrations not exceeding 120 g/L (1 lb/gal) (American Water Works Association and American Society of Civil Engineers, 2005).

Agitator impeller diameters seen in the facilities assessed varied from 1/6 to 1/3 of the tank diameter, with the average impeller diameter being 1/4 of the tank diameter. There were two facilities with impeller diameters of 1/6 of the tank diameter, both of these facilities reported having challenges with settling in the bottom of the slurry mix tank. Of the 14 facilities analyzed three reported no settling in the bottom of the slurry mix tank, these three facilities have impeller to tank diameter ratios of 1/5 to 1/4, it is important to note that the impeller diameter is not the only variable that will affect mixing. Literature suggests that the agitator impeller diameter should be 1/4 to 1/3 of the tank diameter.

Proposed design guideline:

D29. If modeling cannot be undertaken for the slurry tank agitator design the following rules of thumb should be considered:

a. The agitator impeller diameter should be 1/4 to 1/3 of the tank diameter
b. Propeller or axial flow turbine agitator blades are often used on smaller tanks and should turn at approximately 350 rpm. Whereas turbine type impellers are often used on larger tanks and should turn at speeds of 100 rpm or less, and
c. About 1.5 to 1 hp per 3,785 L (1,000 gal) of tank capacity is required for cylindrical tanks of less than 11,400 L (3,000 gal) capacity and slurry concentrations not exceeding 120 g/L (1 lb/gal). Modeling should be undertaken to determine the optimal agitator impeller design as a function of tank size and shape, the specific gravity of the lime mixture, and the settling rate of the suspended solids.

Splashing from the mixer is attributed the solids buildup on the sides of the slurry mix tank walls. Four facilities noted that they had decreased splashing and solids buildup on the sides of the slurry mix tank walls by changing the normal liquid level in relation to the agitator impellers.

Proposed design guideline:

D30. The slurry agitator impellers should be a minimum of one impeller diameter below the normal liquid level. The agitator speed should be set appropriately to ensure good mixing without splashing.

Nine facilities (64%) had agitators that entered the slurry mix tank through the top of the tank parallel to the tank walls, three facilities (21%) had agitators that entered the tank on an incline, one facility did not have an agitator, and one facility did not know how the agitator entered the tank. It is noted for proper mixing, to decrease splashing, and to avoid shaft wear at the seal of the packing of the agitator the agitator should enter the tank through the top of the tank parallel to the tank wall.

Proposed design guideline:

D31. The slurry agitator should enter the tank from the top, parallel to the tank walls. This may decrease the potential for splashing and solids buildup on the walls, promote effective mixing, and decrease wear on the agitator.

Proposed operation and maintenance guideline:

O16. If splashing due to the agitator is an issue, consider changing the slurry mix tank operating level or decreasing the agitator rotational speed, see design guideline 30. Note that the agitator should remain a minimum of one impeller diameter below the normal liquid level.

One facility noted they had experienced challenges with splashing and solids buildup above the normal liquid level in the tank, in order to mitigate this challenge they installed a spray nozzle at the top of the tank to continually wash buildup off of the walls. During the second workshop it was noted, while this is an effective way of mitigating buildup on the sides of the tank, the spray nozzles should be focused on problem areas, and this should only be installed if the tank has a properly designed venting system. Wetting surfaces unnecessarily, and without a properly designed venting system, can lead to build up where there otherwise may be none.

Proposed design guideline:

D32. If splashing and solids buildup above the normal liquid level is an issue, add a spray nozzle at the top of the tank to continually wash buildup off walls. This should only be done if the tank has a properly designed venting system.

8.2.5 Slurry tank level measurement

Five facilities (36%) indicated level measurement in the slurry mix tank was a challenge and 12 facilities noted their level measurement device was accurate.

Figure 10 shows the level measurement devices used for each of the 14 facilities. Note one facility used two different types of level measurement devices.

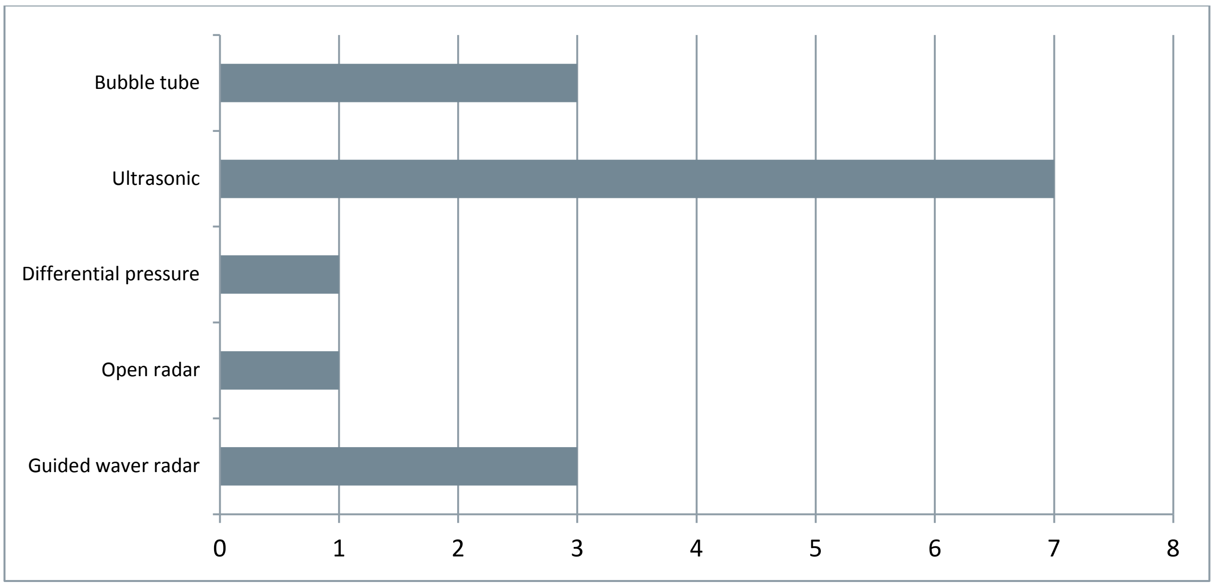

Figure 10 – Slurry tank level measurement devices used

Facilities reported success and failures with many different forms of level measurement. As previously noted, 12 of the 14 facilities represented in Figure 10 reported their level measurement devices were accurate. The two facilities that did not find their level measurement devices to be accurate were using ultrasonic level measurement devices and felt these were inaccurate due to interactions with foam.

Many facilities had experience using several varieties of level measurement devices, the following comments were made during the one-on-one interviews:

- Two facilities noted that they had used radar in the past without success, and
- One facility noted that ultrasonic had not worked for them in the past due to issues with dust. In response they had moved the level transmitting device as far as possible away from the agitator

and the lime powder inlet.

Seven facilities had redundant level measurement devices, these facilities noted that this added certainty to the level measurement process and also made it easier to performance maintenance on the devices. One facility had redundancy in their devices by having two different level measurement devices.

Proposed design guidelines:

D33. Use redundant level measurement in the slurry mix tank; having two different level measurement technologies may add value to this redundancy.

Facilities have reported success with many different forms of level measurement. The two most common forms of level measurement are ultrasonic and bubble tube. Two facilities noted that radar had not worked for them in the past.

There are challenges associated with each level measurement device:

- Bubble tube
    - Significant maintenance is required.
    - There is a greater potential of scaling compared to other devices.

- Radar
    - The cable type that extends into the tank can become cake with material and require maintenance.
    - Both cable and cone types can be affected by dust particulate, creating inaccurate readings.

- Ultrasonic
    - The presence of foam or dust creates inaccurate readings.

D34. Dust can create challenges with level measurement due to buildup on level measurement devices and false readings due to particulate. Locate the slurry mix tank level measurement device away from the lime powder inlet and the agitator if possible.

Seven facilities noted they performed preventative maintenance (PMs) on the slurry mix tank level measurement device, the other seven facilities were unsure if regular PMs were performed. Frequency of PMs varied from once every six hours to once every two weeks.

Proposed operation and maintenance guideline:

O17. Visually inspect the slurry mix tank level measurement device weekly, clean the device as necessary.

8.2.6 Slurry tank inlets and outlet

The slurry mix tank has, at a minimum, a makeup water inlet, a lime powder inlet, and a slurry outlet, depending on the system there may be a slurry recycle inlet.

Three of the 14 facilities assessed had the makeup water inlet on the side of the tank below the normal liquid level. Seven facilities had the makeup water inlet on the top of the tank, and four facilities had it on the side above the normal liquid level.

At the lime handling system workshops it was proposed the makeup water inlet should be below the normal liquid level. It is suggested there may be less issues with splashing if the makeup water inlet is below the normal liquid level. There was some discussion of scale buildup at the water inlet if the water inlet is below normal liquid level however none of the facilities reported this as a challenge. If scale build is a concern flex hose could be used at the water inlet instead of hard pipe, the vibrations of the flex hose may work to prevent a scale ball building up.

Proposed design guideline:

D35. Locate the water inlet below normal liquid level to prevent solids buildup in the tank. Flex hose could be used instead of hard pipe to prevent “build up ball” of scale.

In all of the facilities assessed the lime powder inlet is at the top of the slurry mix tank. Seven facilities indicated that the lime inlet was on the top of the tank to the side, one facility indicated that it was on the top of the tank in the center, and the remaining six facilities simply indicated that it was at the top of the tank. It is recommended that the lime powder should be added to the tank as close to the center of the tank as possible without being at the impeller. In addition, it should be added away from the water inlet to avoid splashing of the powder onto tank walls.

Proposed design guideline:

D36. Lime powder should be added to the tank as close to the center of the tank as possible. The inlet should be close to the agitator shaft so that the powder drops into the vortex formed by the agitator, but should not be on the agitator shaft. Lime powder inlet should not be directly over top of the baffles or agitator to avoid product build up.

Very little information was available regarding the slurry outlet location from the slurry mix tank. During workshops one and two there was discussion surrounding the slurry outlet location, it was noted that the level in most of the tanks is relatively stable however the mixing zone must be considered. Additionally, it must be considered that the area below the outlet may be a dead zone in the tank therefore raising the slurry outlet may create a larger dead zone while decreasing the amount of solids buildup that is sucked into the pump.

Proposed design guideline:

D37. The slurry tank lime slurry outlet should be raised off the bottom of the tank. A proposed minimum based on anecdotal evidence is 30 cm (12”). This may help prevent plugging of the suction nozzles.

9.0 Slurry transfer lines and feed pump

Once the hydrated lime powder has been properly mixed with water it is transferred from the slurry mix tank through slurry transfer lines with a feed pump; some systems have slurry recycle lines that return to the slurry mix tank.

9.1 Results

Table 8 displays data collected regarding the slurry transfer lines and feed pump. The core equipment and process components and the challenges experienced at each facility are shown. The major challenges in relation to slurry transfer lines and feed pump were:

- Line plugging due to scaling
- Plugging of the inlet to the reactor
- Plugging of the feed pump suction nozzles
- Line plugging due to settling
- Wear on the feed pump impeller
- Scaling on the feed pump, and

- Valve erosion on the slurry transfer lines.

Additional challenges were:

- Plugging of the recirculation lines
- Under designed feed pump
- Problems with pinch valves, and
- Frequent cleaning of lines required.

Figure 11 illustrates the number of facilities that experienced each challenge identified with the slurry transfer lines and feed pump.

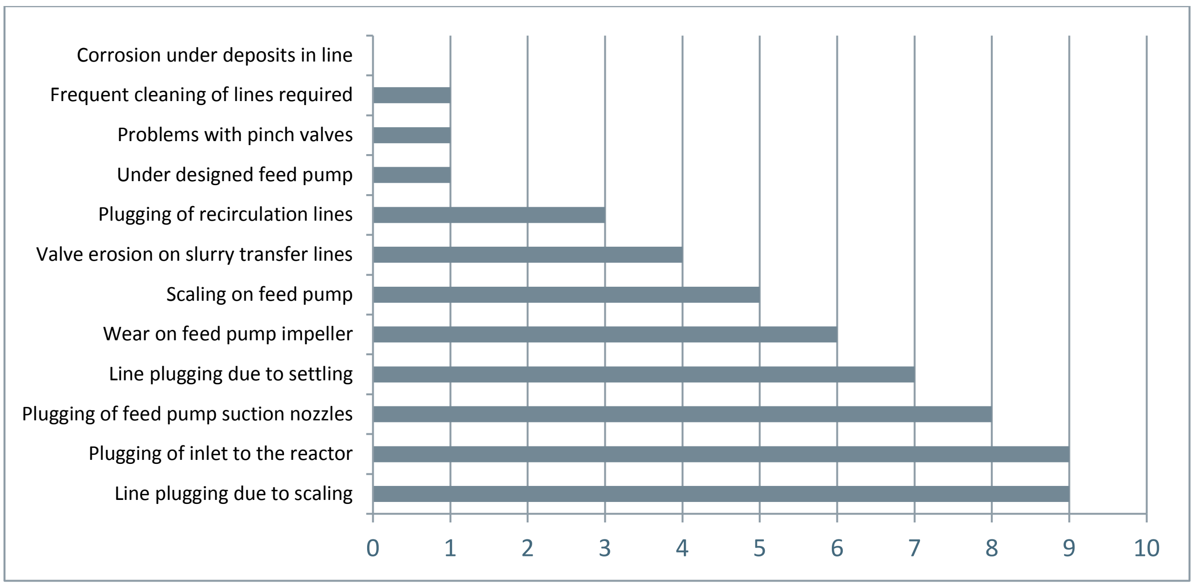

Figure 11 – Challenges associated with the slurry transfer lines and feed pump

Table 8 – Equipment and challenge matrix – slurry transfer lines and feed pump

			Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Core equipment & Process Components	Line Size (inches)		1.5"	1.5"	2"	2"	4"	4"	3" reduced to 2"	3"	Suction: 2-1/2" Discharge & recirc.: 2"	3" pump suction 2" pump discharge / recirc.	2"	2"	1.5"	2"
	Line Type	Hard pipe	X[1]	X[1]	X[3]	X[3]	-	-	X	X	-	X	X	X	X	X
		Flexible pipe	-	-	X[3]	X[3]	-	-	-	-	-	-	-	-	-	-
		Flanged flex hose	-	-	-	-	-	-	-	-	X	-	-	-	-	-
		Fiberglass	-	-	-	-	X	X	-	-	-	-	-	-	-	-
		Hose	X[1]	X[1]	-	-	-	-	-	-	-	-	-	-	X	-
		Pipe material	Fire hose and teflon lined pipe	Fire hose and teflon lined pipe	Hose and Carbon steel	Hose and Carbon steel	FRP	FRP	Carbon Steel	Carbon Steel	ASTM A106B, SMLW	Carbon steel	A106-B CS	Carbon steel	Carbon steel and flexible hose	Carbon steel
	Recirculation Line	Is there a recirculation line?	No	No	No	No	Yes	Yes	Yes	No	Yes	No (not used)	Yes (not used)	Yes (not used)	No	Yes
		Continuous flow?	-	-	-	-	Yes	Yes	Yes	-	No	-	-	-	-	Yes
		Slope	-	-	-	-	Unknown - uphill in some sections			-	0	-	-	-	-	1%
	Water Quality	Water Source	BFW	BFW	Supernatant	BFW	BFW	BFW	Brackish Water	Soft brackish water	Steam condensate	Blowdown Flash Condensate	BFW	BFW	Mixed BFW & fresh water	Raw water
		Temperature	35 - 45	35 - 45	10 - 20	< 40	40	40	20 - 25	10 - 20	45	20 - 40	< 40	< 40	5 - 40	5 - 15
		pH	9.6 - 10.2	9.8 - 10.2	9 - 10	9.3 - 9.5	9.0 - 9.5	9.0 - 9.5	9.4	8	8 - 8.7	7.8	9.9	9.9		7.8
		TOC (ppm)			150 - 200	100 - 200	170		3	5 - 15	<150	127				
		Conductivity (µS/cm)	<10,000	<10,000	20		11,000		12,700	12,000 - 14,500	12,000 - 15,000	150	8,000 - 10,000	7,000 - 11,000		450
		Total Alkalinity (mg	481	481	80 - 100	60 - 80	550 -		783	520 - 590	Not	88	625 - 700	350 - 550		240

	$CaCO_3$)					750				measured					
	Bicarbonate Alkalinity (mg $CaCO_3$)	308	308	10	10			387	640 - 720	Not measured	88	200 - 300	75 - 175		290
	Hardness (mg $CaCO_3$)	0.5	0.5	0 - 300	< 0.3	0.2 - 1.0		4.9	< 10	<0.075	<0.25	< 0.2	< 0.5		210
Slurry	What is the slurry concentration goal?	None	None			5 % - 10%	5 % - 10%	2.5 - 3% by weight, 10 - 12% by volume	3-5 v/v%	5 - 10 wt%	~ 5% vol (1-2% wt) not critical	None	None		1.1 g/cm3
	Slurry Velocity (m/s)					~1.5	0.7 - 1.5	1.08	0.7	Suction: 1.6 Discharge: 2.7	0.6 - 1.5	2.5	2.5	1.5 - 2.0	3.7
	Is slurry aid added (either to the tank or the transfer lines)?	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No
	Where is slurry aid added?	-	-	-	-	Slurry tank	-	-	-	-	-	-	-	-	-
Slurry Pump	Type of pump	Centrifugal (Inline vertical pump)	Centrifugal (Wilfey)		Centrifugal	Centrifugal side suction	Centrifugal side suction	Centrifugal side suction slurry pump	Wilfley K-Pro slurry pump	Centrifugal end suction top discharge	Centrifugal	Centrifugal	Centrifugal	Wilfley - A7, centrifugal end suction	Centrifugal end suction
	VFD	Yes[2]	Yes[2]	No	Yes	No	No	Yes	Yes	No	No	Yes	Yes	Yes	No
	Permanent water flush lines	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No
	Flush procedure (for batch)			-	-	Yes	Yes	-	-	No	Yes	-	-	-	No
	Automatic flush procedure (for continuous)			No	No	Manual	Manual	No	No	No	N/A	Manual	N/A	No	No
	Flush frequency	-	-	-	Every 12 hours	As required	As required	-	-	No routinely flushed	Weekly as needed		-	As needed	-
	Flush duration	-	-	-		As required	As required	-	-	-			-	-	-
Valves	Size	3" and 2"	3" and 2"	2"	2"	3"	3"	3"	3"	Per line size	Per line size	2"	2"	1.5"	2"

		Pinch	-	-	-	-	-	-			X	X	-	-	X	
		Plug	X	X	-	-	-	X	X		-	-	-	-	-	
		Ball	-	-	X	X	-	-			-	-	-	-	-	
		Gate	-	-	-	-	-	-	X	X	X	-	X	X	-	
		Diaphragm	-	-	-	-	X	X			-	-	-	-	-	
	Flow Rate	How is it measured?			Tank make up output	Flow meter	-	-	Magmeter	Inline magnetic flow meters	Flow meter	Mag meter	Mag meter	Mag meter	Magnetic flowmeter	Flow meter
		How is it controlled?	Pump - manual VFD	Pump - manual VFD	Throttling discharge valves	VFD on pump	Makeup water to slurry tank	Makeup water to slurry tank	Feedback to pump VFD	Feedback frontrol from flowmeter to pump VFD	WLS pH	Manual control valve	Tank level	Tank level	VFD on pump	Solenoid FV
	PMs?	Are there PMs?	Yes	Yes			No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
		PM	Changed every 6 months	Changed every 6 months			-	Steam and acid washed every 6 months	Cleaned every 4 weeks	Cleaned every 10 - 12 weeks with inhibited HCl	Acid wash - 8 weeks	Acid wash quarterly	Acid wash - 8 months	Acid wash - 8 months	-	Cleaned two annually
	Batched out of tank		No	No	No	No	No	No	No	No	Yes	No	No	No	No	Yes
	Continuous with recycle		-	-	-	-	X	X	X	-	-	-	-	-	-	-
	Batched with recycle		-	-	-	-	-	-	-	-	X	-	-	-	-	X
	Once through system		X	X	X	X	-	-	-	X	-	X	X	X	X	-
	Is there settling at the bottom of the slurry mix tank		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Challenges	Line plugging	Settling	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	No	Yes	No
		Scaling	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes
	Wear on feed pump impeller		No	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	Yes	No
	Scaling on feed pump		No	No	Yes	Yes	No	No	Yes	Yes	No	No	No	No	Yes	No
	Under designed pump		No	No	No	No	No	No	No	No	Yes	No	No	No	No	No
	Plugging of feed pump suction nozzles		Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	Yes	Yes
	Valve erosion on slurry transfer lines		No	No	No	No	Yes	Yes	No	Yes	No	Yes	No	No	No	No
	Problems with pinch valves		-	-	-	-	-	-	-	-	No	Yes	No	No	-	-
	Plugging of inlet to the WLS / HLS		Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes	Yes
	Plugging of recirculation lines		-	-	-	-	Yes	No	Yes	-	Yes	-	-	-	-	No
	Frequent cleaning of lines required		-	-	No	No	No	No	No	No	No	No	No	No	Yes	No
	Corrosion under deposits in line		No	No	No	No	No	No	No	No	No	No	No	No	No	No

Notes:

1. Hard pipe (teflon lined) on pump inlet, fire hose on outlet.

2. Not used - pumps are maxed.
3. Flex hose out of the slurry tank to the pump, hard pipe after pump.
4. Batch: Full batch system, slurry is batched out of the slurry mix tank.
5. Continuous with recycle: Constant flowrate of lime slurry out of the slurry mix tank, the volume of slurry sent to the downstream reactor is controlled downstream of the mix tank with a control valve or a VFD on the lime feed pump.
6. Once through: Constant flowrate of makeup water to the slurry mix tank, constant flowrate of slurry out of the slurry mix tank and into the downstream reactor and varying amounts of lime powder being added to the slurry mix tank.

9.2 Analysis

The major components of the lime handling system downstream of the slurry mix tank are the transfer lines, the slurry transfer line components and the slurry transfer pump.

The major recommendation for system owners is to develop a lime system piping specification to help manage the challenges unique to the system.

Proposed design guidelines:

D38. Create a pipeline specification specifically for the lime system including smooth walled hose and Victaulic or clamp style couplings.

D39. Minimize pressure drop in the slurry piping system. Minimize dead legs in slurry transfer lines. Minimize the slurry transfer line length and direction change in lines to prevent plugging. Where elbows are necessary use long radius elbows. Avoid use of vertical pipelines.

D40. Avoid reduced pipe diameter sections and instrumentation or controls on the lines to prevent solids buildup and plugging in these locations. If reduced pipe diameters are necessary, reductions must not be so abrupt that they can cause a violent hydraulic disturbance that can result in dewatering and compaction of the lime.

9.2.1 Lines

Line plugging was reported at 10 out of 14 facilities (71%) assessed. Six facilities attributed line plugging to both settling and scaling, three facilities attributed line plugging to scaling, and one facility attributed line plugging to settling.

Figure 12 shows the pipe material used at each facility.

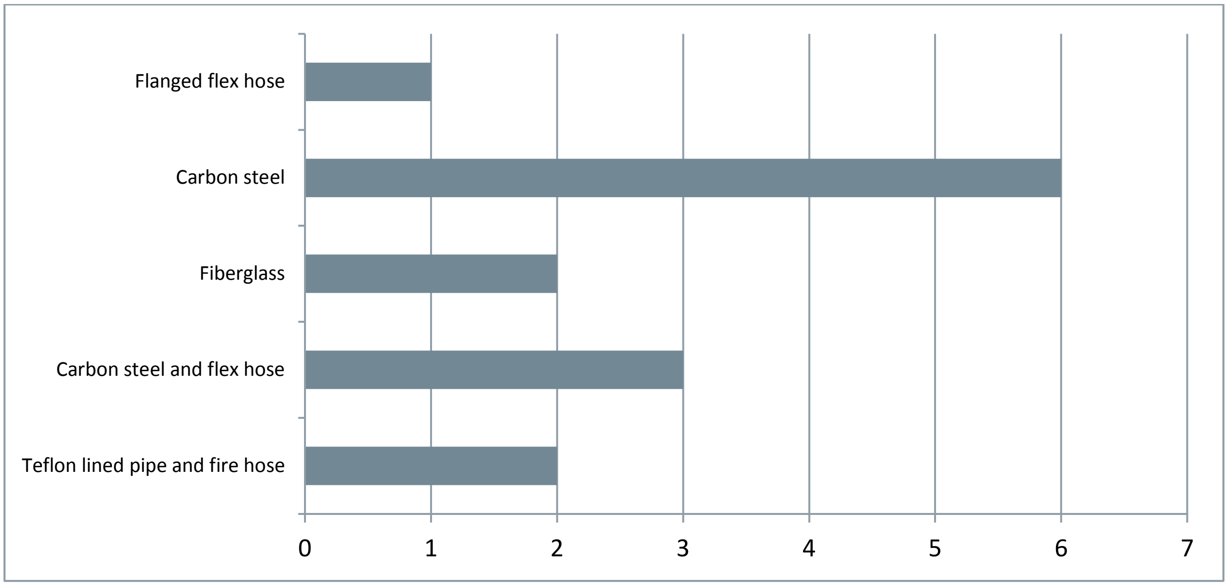

Figure 12 – Slurry transfer line material used

There appears to be no correlation between pipe material use and line plugging from either settling or scaling. Five participating facilities noted that, after having challenges with plugging of their transfer lines, they changed their piping system from a full hard pipe system to a partial or full hose system. It was noted hose can be changed quickly and lime solids can be removed by flexing the pipe and rinsing it.

Line size varied in the facilities assessed from 1.5” to 4”. Three facilities had 1.5” lines and all of these noted challenges with line plugging due to both scaling and settling. Two facilities had lines at 4”, only one of these facilities reported challenges with line plugging due to settling and neither facility reported challenges with line plugging due to scaling.

Because line plugging is a common challenge, and because there are many factors that affect line plugging there can be no conclusions drawn between line plugging and pipe sizing. However, it is known lime transfer lines are prone to scaling and setting; this should be considered when pipe size is determined. In workshops one and two it was suggested lines should be a minimum of 2”, however 3” is preferable.

Slurry velocity is known in 10 of the 14 facilities assessed, velocity range from 0.6 to 3.7 m/s. Velocities can be seen in Table 8. Facilities that reported consistently higher slurry velocities also reported fewer challenges with slurry transfer line plugging due to settling. Seven facilities reported having no challenges associated with plugging of the transfer lines due to settling, where known the slurry velocities at these facilities were reported to be 1.5 m/s or greater. Facilities that had lower velocities reported that they were making an effort to increase the slurry transfer velocities to decrease plugging challenges. Literature supports the thought that increasing velocity may help to decrease line plugging – “to control transfer pipe plugging due to settling, but avoid excessive abrasion, ensure the slurry velocity is between 1.2 m/s and 3 m/s” (National Lime Association, 1995).

Proposed design guidelines:

D41. Solid pipe, flex pipe, or flex hose can be used for the slurry transfer lines. If line plugging is a challenge consider using smooth walled hose for slurry transfer lines to provide easy maintenance, and/or replacement. Consider using hose in the pump suction line between the slurry mix tank and the pump to facilitate cleaning.

D42. Higher velocities have shown a strong correlation with reduced settling in pipes, a slurry velocity between 1.2 m/s and 3 m/s is recommended. Ensure that the proper hydraulic calculations surrounding settling velocity are completed. Higher velocities will require high pressures to overcome losses and therefore will require more expensive equipment. This should be considered in making decisions on pump and pipeline design.

D43. Use VFD's over control valves for slurry dosing control to reduce potential control valve erosion and slurry control issues. Ensure VFDs do not allow slurry velocities to fall below the suggested design minimum of 1.2 m/s.

D44. A permanent water flushing system should be in place for removing slurry from pumps, piping, and valves upon system shut-down. The flushing system should be automatic if shut-down is automatic (Beals, 1976). The flush lines should be connected upstream of the pumps.

Five out of 14 facilities (36%) assessed used recirculation lines at their facility; at least two other facilities had recirculation lines installed at their facility but did not use the lines during regular operations. Four of the facilities (80%) that had recirculation lines reported challenges with plugging of the recirculation lines. It was widely recognized that if recirculation lines are used the lines should comply with all slurry transfer line guidelines.

Proposed design guidelines:

D45. Facilities with recirculation lines report more challenges with slurry settling in lines than those without recirculation lines. The use of recirculation lines is not recommended unless site specific design parameters require them.

D46. If recirculation lines are used at the facility, flow should be continuous through the lines to avoid settling. The slurry velocity in the recirculation lines should be between 1.2 m/s and 3 m/s.

D47. If recirculation lines are used lines should be sloped to promote gravitational flow to decrease plugging. Overall line guidelines should be followed, see guideline 39.

D48. If recirculation lines are used place the recirculation line take off at a system high point and as close to the reactor as possible.

9.2.2 Valves

Valve erosion on slurry transfer lines was reported at four (29%) of the facilities assessed. Most of these facilities used a single valve type; however one facility employed two valve types. Valve types seen at facilities were ball valves, pinch valves, plug valves, gate valves, and diaphragm valves. The facilities that reported valve erosion challenges used diaphragm valves, plug valves, gate valves, and pinch valves. These same valve types were present at facilities that did not report valve erosion issues.

Due to the variety of valves, strong correlations between valve types and valve erosion could not be made. In the workshops several facilities noted they had changed out pinch valves in the past and, in the one-on-one interview, one facility reported they were replacing pinch valves with plug valves due to valve erosion issues.

Proposed design guideline:

D49. Avoid using valves for flow control, see design guideline 43. In the event that a valve must be used for flow control, avoid pinch valves as they are easily eroded and may fail. Use knife gate valves for manual control / isolation. Consider using plug valves if pinch valves are found to be unreliable.

Proposed operation and maintenance guidelines:

O18. Pinch valves used for modulation should be "pulsed" (fully open then fully closed, regulating flow with the duration of closure rather than orifice size) instead of partially opened to preserve lifetime.

O19. Stroke control valves fully open / fully closed monthly to help reduce buildup.

Facilities that reported having very few valves, or having only isolation valves, did not report any operating challenges associated with valve.

Proposed design guidelines:

D50. Minimize the number of valves on the transfer lines to reduce erosion and plugging.

D51. Do not use check valves in the slurry transfer system, check valves are prone to becoming plugged and remaining open.

D52. Consider using single block isolation valves to help reduce the number of valves used.

D53. If possible valves should be placed in vertical orientation so that debris falls vertically through the valves during open and closure rather than settling in horizontal connections.

9.2.3 Pump

The most frequently reported challenges with the slurry feed pump was plugging of the pump suction nozzle, this challenge was seen in eight of the 14 facilities (57%) assessed. Having a water flush line upstream of the pump and flushing the pump before it is shutdown will help with feed pump plugging. See design guideline 44. Additionally, running a "once through" slurry system, as discussed in 7.2.2, has been seen to decrease plugging of the pump suction nozzle.

Proposed operation and maintenance guidelines:

O20. Backup pumps should be isolated and flushed before and after use.

O21. "Start and stop" operation can lead to plugging of the pump suction nozzle. Running a high flowrate with low slurry concentration had been seen to decrease pump suction nozzle plugging.

All of the pumps used at the facilities assessed were centrifugal pumps. One owner who reported on two facilities noted that they had a slurry pump installed at one of their facilities and a water pump installed at the other. They noted that the slurry pump was much more effective than the water pump, the water pump tended to scale off more quickly and wear out more quickly than the slurry pump.

Proposed design guidelines:

D54. The valves and piping surrounding the slurry feed pump should be designed to allow for isolation and flushing of backup pumps before and after use.

D55. Use a slurry pump, many participants noted that a slurry pump is better than a water pump as slurry pumps don't scale or wear as quickly as water pumps.

D56. Pumps should be sized to maintain a minimum velocity of 1.2 m/s in the transfer lines. If recycle lines are used the pump should be sized to maintain a minimum velocity of 1.2 m/s in the recycle lines.

10.0 Water quality and temperature

The water quality and temperature of the water mixed with the hydrated lime powder can create system challenges such as humidity issues and scaling in the slurry mix tank and lines. The challenges associated with water quality have been addressed in other sections of this report as they are closely tied to the lime handing system design.

10.1 Results

Table 8 displays the data collected regarding water quality and temperature. Water quality information and challenges experienced at each facility are shown. The major challenges associated with water quality are:

- Overall system moisture control challenges
- Slurry mix tank vent plugging
- Foaming in the slurry mix tank, and
- Scaling in the slurry mix tank and slurry transfer lines.

Figure 13 illustrates the number of facilities that experienced each challenge identified with the water quality and temperature; the figure shows the number of facilities that experienced each challenge out of a total of 14 facilities that were analyzed.

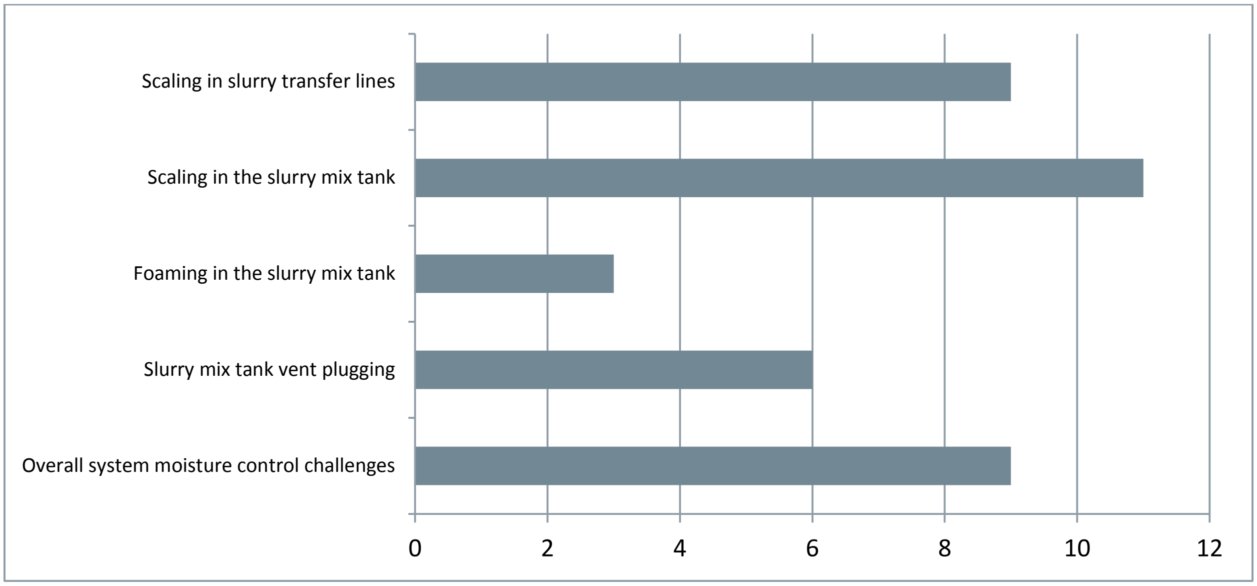

Figure 13 – Challenges associated with the water quality and temperature

Table 9 – Equipment and challenge matrix – water quality and temperature

		Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Water Quality	Water source	BFW	BFW	Supernatant	BFW	BFW	BFW	Brackish Water	Soft brackish water	Steam condensate	Blowdown Flash Condensate	BFW	BFW	Mixed BFW & fresh water	Raw water
	Temperature (°C)	35 - 45	35 - 45	10 - 20	< 40	40	40	20 - 25	10 - 20	45	20 - 40	< 40	< 40	5 - 40	5 - 15
	pH	9.6 - 10.2	9.8 - 10.2	9 - 10	9.3 - 9.5	9.0 - 9.5	9.0 - 9.5	9.4	8	8 - 8.7	7.8	9.9	9.9		7.8
	TOC (ppm)			150 - 200	100 - 200	170		3	5 - 15	<150	127				
	Conductivity (µS/cm)	< 10,000	< 10,000	20		11,000		12,700	12,000 - 14,500	12,000 - 15,000	150	8,000 - 10,000	7,000 - 11,000		450
	Total alkalinity (as mg $CaCO_3$)	481	481	80 - 100	60 - 80	550 - 750		783	520 - 590	Not measured	88	625 - 700	350 - 550		240
	Bicarbonate alkalinity (as mg $CaCO_3$)	308	308	10	10			387	640 - 720	Not measured	88	200 - 300	75 - 175		290
	Hardness (as mg $CaCO_3$)	0.5	0.5	0 - 300	< 0.3	0.2 - 1.0		4.9	< 10	<0.075	<0.25	< 0.2	< 0.5		210
Slurry mix tank vent	Is there a vent?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes[3]	Yes	Yes	Yes	Yes	No
	Vacuum on vent	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	-
	How is vacuum created?	Eductor	Eductor	Induced draft fan	Induced draft fan	Induced draft fan	Draft fan (not induced)	Induced draft fan	Induced draft fan (not in-line)	-	Natural circulation /convection	Eductor	Eductor	Air driven venturi	-
	Wet scrubber on vet	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	Yes	-
	Vents outside	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	-
Challenges	Overall system moisture control challenges	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No	Yes	Yes	Yes
	Slurry mix tank vent plugging	Yes	Yes	Yes	No	No	No	Yes	No	No	No	No	Yes	Yes	No
	Foaming in the slurry mix tank	No	No	No	No	Yes	Yes	No	No	Yes	No	No	No	No	No
	Scaling in the slurry mix tank	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Scaling in slurry transfer lines	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes

10.2 Analysis

Nine of 14 facilities (64%) assessed reported challenges with overall lime handling system moisture control challenges and six of 14 facilities (43%) reported challenges with slurry mix tank vent plugging. These challenges are interconnected and can be associated with high water temperature causing moisture in the tank and upstream of the tank. The reported water temperature at the facilities assessed varied from 10°C to 45°C. The reported temperatures varied greatly even at one facility.

Facilities with cooler water temperature report fewer issues with plugging upstream of the slurry mix tank, even if the tank does not have a functional vent. Although water temperature is an important consideration it is also important to note a properly functioning vent on the slurry mix tank can help mitigate water temperature issues (see guidelines 20 to 25 for slurry mix tank vent design considerations). A properly functioning vent is a more cost effective way to deal with humidity issues than installing additional heat exchangers to further cool the water.

Proposed design guideline:

D57. Water temperature should be as cool as practice. 25°C is an ideal water temperature and a maximum water temperature should be 40°C. Lime solubility decreases as water temperature increases, see Figure 14.

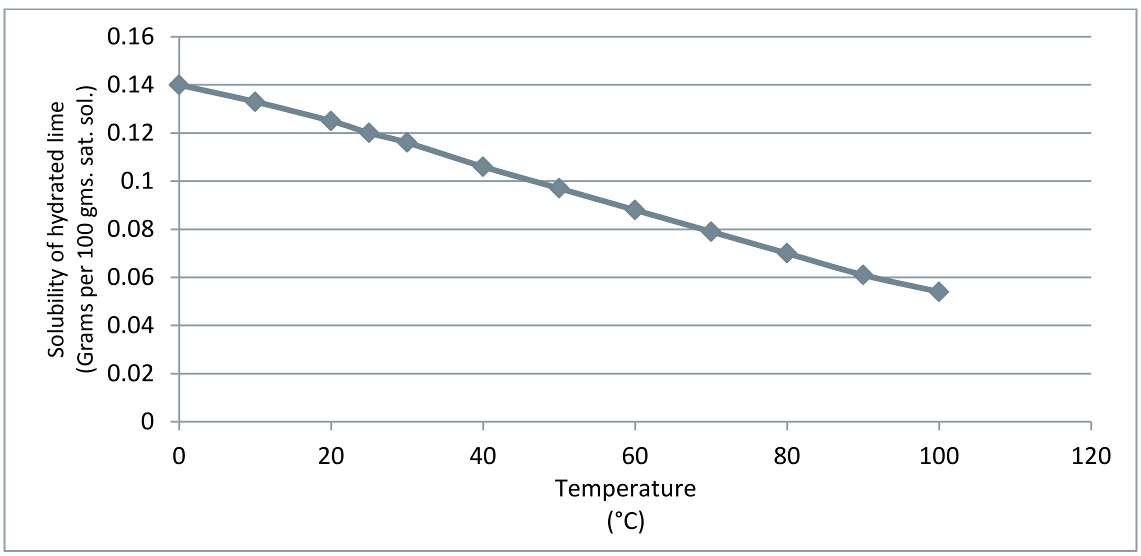

Figure 14 – Solubility of lime with increasing water temperature (National Lime Association)

High calcium hydrated lime does not need to be slaked at site; because it is already hydrated there are fewer interactions with water. However, because of lime's inherent high pH of 12+, the water that carries the lime undergoes a softening action and precipitates fresh calcium carbonate as a dense, hard scale.

Hassibi (2009) noted that water with high dissolved solids generally causes excessive foaming during lime slaking, and water containing over 500 mg/L of sulfates or sulfites are unsuitable for slaking. This also refers to lime slaked at site, where it is likely the same impurities in the water would cause foaming, to a lesser extent, in hydrated lime handling systems.

Proposed design guidelines:

D58. The lime slurry tank should be treated as a reactor in terms of water quality and chemical interactions. The pH in the tank is typically around 12. The water quality characteristics should be considered to reduce scaling of equipment. Increased impurities will increase scaling challenges.

D59. Minimize alkalinity in slurry makeup water. This will decrease scaling in the slurry mix tank and downstream of the mix tank. Foaming in the slurry mix tank may also be decreased when alkalinity and hardness are minimized.

11.0 Lime handling system preventative maintenance

Proper design of a lime handling system will add to the ease of operating the system; however maintenance must be carried out on the system to ensure it continues to run efficiently.

Preventative maintenance will not eliminate challenges with the lime handling system; however it will help mitigate challenges and will decrease system downtime.

11.1 Results

There was a general lack of knowledge or awareness surrounding preventative maintenance schedules among participants. Many participants noted there may be a preventative maintenance schedule they were unaware of, and others noted preventative maintenance was not carried out although it should be.

Table 10 displays the data collected regarding preventative maintenance at participating facilities.

Table 10 – Preventative maintenance schedules

	Facility 1	Facility 2	Facility 3	Facility 4	Facility 5[2]	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Silo level measurement device	None	None			None	None	3 months	2 weeks					None	
Silo bin filter	Cleaned or replaced every 6 months	Cleaned or replaced every 6 months	Annually	Annually	Cleaned or replaced every 3 months	Cleaned or replaced every 3 months							None	
Silo PVRV	None	None											None	
Rotary valve	6 months	N/A	Calibrate quarterly, change as needed (~6 months)				Switched annually	No	N/A				None	
Hopper	6 months, clean and calibrate weight scale	N/A											None	
Screw Conveyor	Cleaned every 6 months	Cleaned every 6 months			Annual lubrication	Annual lubrication							None	
Chute					Weekly	Weekly							None	
Tank Vent	Cleaned every 1 month	Cleaned every 1 month							N/A	None	Visual - Monthly Open - 2 months		None	
Tank Level Measurement	Visual every 2 weeks	Visual every 2 weeks	Every 6 hours the bubble tubes are blown out with water and air	Every 6 hours the bubble tubes are blown out with water and air	Cleaned every 2 weeks	Cleaned every 2 weeks							None	
Tank	Acidized every 2 weeks	Acidized every 2 weeks	Cleaned every 4 months	-	None	Cleaned annually	Cleaned monthly	Cleaned every 10 - 12 weeks	Acid cleaned ~ every 2 months[1]	Cleaned quarterly with sulfamic acid	Acid washed every 8 months	Acid washed every 8 months	Cleaned every 2 - 3 months with pressurised water	The inside of the tank is checked every 6 months

	Facility 1	Facility 2	Facility 3	Facility 4	Facility 5[2]	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14
Pumps	Acidized every 2 weeks	Acidized every 2 weeks	Rylie every 1 - 3 months for 12 - 24 hours	Rylie every 1 - 3 months for 12 - 24 hours	None	Steam and acid washed every 6 months			Acid cleaned ~ every 2 months1	Cleaned quarterly with sulfamic acid, flushed weekly	Acid cleaned every quarter	Acid cleaned every quarter	None	
Transfer line valves					Change diaphragm valves on a 90 day PM schedule	Change diaphragm valves on a 90 day PM schedule							None	
Transfer lines	Changed every 6 months	Changed every 6 months			None	Steam and acid washed every 6 months	Cleaned every 4 weeks	Cleaned every 10 - 12 weeks with inhibited HCl	Acid cleaned ~ every 2 months	Cleaned quarterly with sulfamic acid	Acid washed every 8 months	Acid washed every 8 months	None	Scale is removed every 6 months (method unknown)

Notes:

1. Tanks are acid cleaned when the lines are acid cleaned.
2. Slurry aid is added, reduces cleaning requirements in the slurry mix tank and downstream.
3. Shaded cells indicate unknown PM schedules.

11.2 Analysis

Based on the information presented in Table 10, and discussion during the second workshop, Table 11 presents a suggested preventative maintenance schedule. It is important for facilities to have a preventative maintenance schedule and it is suggested Table 11 should be used as a starting point to be adapted to each facility's needs.

Table 11 – Suggested preventative maintenance schedule

	Preventative maintenance suggestion	Frequency
Silo level measurement device	Verification	3 months
Silo filter	Visual PM - cleaning or replacement if necessary	3 months or 10 offloads
Silo PVRV	Visual PM - cleaning or replacement if necessary	3 months or 10 offloads
Rotary valve	Visual PM, change as needed Calibrate are necessary	6 months
Hopper	Visual PM, clean as needed Calibrate if necessary	6 months
Screw conveyor	Visual PM, clean as needed Calibrate if necessary	6 months
Chute	Visual PM, clean as needed	Monthly
Tank vent	Cleaned	Monthly
Tank level measurement	Visual and cleaning as needed	Every 2 weeks
Tank	Acid clean	Every 2 weeks - 8 months
Pumps	Acid clean	Weekly - 3 months
Transfer line valves	Visual PM, cleaned as needed Change valves if necessary	3 months
Transfer lines	Acid washed Changed if hose	Monthly - 8 months

12.0 Summary of guidelines

For a summary of the design guidelines and the operational and maintenance guidelines developed for lime handling systems please refer to the executive summary at the beginning of this report or the *Hydrated lime handling systems for thermal enhanced oil recovery: Toolkit* report, openly available online at http://albertawatersmart.com/featured-projects/best-practice-guidelines.html

13.0 Conclusions

Upon completion of two workshops, one-on-one interviews, and assessment of 14 high calcium hydrated lime handling systems, 59 proposed design guidelines and 21 proposed operation and maintenance guidelines were developed.

The impact of suppliers and consultants on the design and operation of lime handing systems was observed and discussed throughout this work. Similar conclusions were observed during the MgO guideline development (WaterSMART, 2014). The specifications provided by the facility owner to purchasing, or to the design engineer who in turn provides specifications to purchasing, are the most effective way to ensure that important parameters are translated into the hardware.

In the absence of owner's specifications, the process for tender and award of equipment and design contract may create a situation where suppliers provide the lowest cost design to win the contract. If the lime handling system specifications are not detailed enough, the supply chain process may not provide the most effective or efficient equipment.

A major recommendation is that owners use the guidelines proposed to develop their own specifications for lime handing systems. Many operators indicated they will carry these guidelines forward. Doing so in a formal way will ensure that engineering companies are aware of the guidelines and are in a better position to support their implementation.

There were challenges with all major components. Correlations between challenges and design and operation of the system could not always be made, or statistical evidence was note strong. Where this was true, guideline development was supported with anecdotal evidence and documented literatures, as indicated in the analysis.

14.0 Recommendations

Throughout this work there was an enormous amount of data compiled; this data can be seen in tables throughout the report and in Appendix 1. All data was analyzed as it related to the challenges identified in the workshops. The remainder of the data was not analyzed in detail due to project constraints.

There were a number of issues raised throughout this work that were outside of the scope or did not have a substantial enough evidence base to back up guideline suggestions. These topics may be of interest to operators, for example, the addition of slurry aid was discussed, however there were only two facilities that had used it, one with success and one without. Another topic that may be of interest is the mixing of lime and MgO in the same tank. There is potential for these topics to be further investigated should there be an interest.

Throughout the workshops and one-on-one interviews participants identified future work that could advance lime handing system understanding and performance. Additional research and discussion in the following areas may be useful:

- Development of a business case for making changes to specific facilities to increase efficiency and reliability
- Development of a troubleshooting checklist. Operators of existing systems would benefit from a troubleshooting checklist; this would enable quick reference to identify potential solutions to challenges experienced on site
- Development of a stronger basis for routine checks and tests, and
- Development of a website to host lime handling system guidelines and any identified reference materials.

Periodic updates to these guidelines are suggested based on company monitoring and use of the guidelines. This suggestion is reflective of feedback heard since the development of the MgO guidelines. If a guideline is found to be incomplete or if there is further evidence that supports the use of a guideline it is important to document and distribute this updated information. These updates and other best practice guideline collaborative work will be further pursued by Alberta WaterSMART based on interest from the participating companies.

15.0 References

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National Lime Association. Properties of typical commercial lime products. (online). Retrieved from: http://www.lime.org/documents/lime_basics/lime-physical-chemical.pdf. (Accessed 10 June 2016).

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Appendix 1 – Equipment matrix

		Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12	Facility 13	Facility 14	Facility 15
Lime Product	Where is the product obtained?	Univar - Graymont - Exshaw	Univar - Graymont - Exshaw	Graymont	Graymont	Graymont	Graymont	Graymont	Graymont	Univar	Graymont Exshaw (via Univar)	Graymont	Graymont	Graymont	Graymont	Graymont
	What is the product designation/type?	Hydrated Lime	Hydrated Lime	Hydrated Dry Powder	Hydrated Dry Powder	Hydrated Lime	Hydrated Lime	High Calcium Hydrated Lime	Hydrated lime	Hydrated Lime	Hydrated Lime	Hydrated Lime	Hydrated Lime	High Calcium Hydrated Lime	High Calcium Hydrated Lime	
Raw Water Quality	What is the water source (e.g. BFW, steam condensate, etc.)	BFW	BFW	Supernatant	BFW	BFW	BFW	Brackish Water	Soft brackish water	Steam condensate	Blowdown Flash Condensate	BFW	BFW	Mixed BFW & fresh water	Raw water	Cooled distillate
	Temperature (°C)	35 - 45	35 - 45	10 - 20	< 40	40	40	20 - 25	10 - 20	45	20 - 40	< 40	< 40	5 - 40	5 - 15	38
	pH	9.6 - 10.2	9.8 - 10.2	9 - 10	9.3 - 9.5	9.0 - 9.5	9.0 - 9.5	9.4	8	8 - 8.7	7.8	9.9	9.9		7.8	8.6
	TOC (ppm)			150 - 200	100 - 200	170		3	5 - 15	<150	127					0
	Conductivity (µS/cm)	< 10,000	< 10,000	20		11,000		12,700	12,000 - 14,500	12,000 - 15,000	150	8,000 - 10,000	7,000 - 11,000		450	
	Total Alkalinity (as mg $CaCO_3$)	481	481	80 - 100	60 - 80	550 - 750		783	520 - 590	Not measured	88	625 - 700	350 - 550		240	
	Bicarbonate Alkalinity (as mg $CaCO_3$)	308	308	10	10			387	640 - 720	Not measured	88	200 - 300	75 - 175		290	
	Hardness (as mg $CaCO_3$)	0.5	0.5	0 - 300	< 0.3	0.2 - 1.0		4.9	< 10	<0.075	<0.25	< 0.2	< 0.5		210	0.2
Lime Powder Silo	Does the lime transfer line have a target box?	No	No	No	No	No	No	Yes	Yes	Yes	No			No	No	Yes
	How many powder outlets does your silo have?	1	1	2	2	1	1	1	1	1	1	1	2	1	1	1
	What is the silo capacity? (m^3)[6]	220	198.9		325	554	554	103	103	200	266	241	254	379	127.5	
	What is the silo diameter?	4690 mm OD	5630 mm ID	6566 mm	5630 mm	9060 mm	7970 mm	3962 mm	3937 mm	4267 mm	4267 mm	4240 mm	4240 mm	6560 mm	3750 mm	4000 mm
	What is the angle of the silo cone?			60	60	60	60	60	60	60	60	60		26	70	

	What type of filter is on the silo bin vent?	Air backwash bin vent filter	Air backwash bin vent filter	Bag house	Bag house, reverse air purge	Baghouse	Cartridge style	Pneumatic cartridge (vibrating)	Pneumatic cartridge (pulse jet)	Bag filter	Cartridge style	Cartridge filter elements (14)	Cartridge filter elements (7) WAM silo top series	WAM, Pulse-jet type w/ polyester cartridges	Round filter FC-4J39	Passive bag filter
	What capacity is the vent sized for? (m^3/h)					2125	1700			1274	1428		2,549			2208
	What is the vent filter area? (m^2)	24	26		26		26	24	24.5		26	24	24.5	24		
	Design air-to-cloth ratio (m/min) (calculated)						1.09				0.92		1.734			
	What is the filter material?	Polyester Type	Carbon steel		Polyester PTFW Coated	Cartridge	Polyester felt			Polyester Sateen "Snap-in" bags	Synthetic fibre	Spunbound polyester	Polypleat	Polyester cartridges	Polyester	Pleated non-woven polyester
	What sort of level measurement device does your silo have?	Guided Wave Radar	Guided Wave Radar	Load Cell	Load Cell	Cone Radar	Cone radar	Ultrasonic	Radar	Radar	Radar	Guided radar, Level switch	Guided radar, Level switch	Radar	Ultrasonic	Radar
	Does the level measurement device have an air purge?	No	No	-	-	Yes	Yes	No	No	No	No	No	No	Yes	No	
	What are the PVRV set points?															
	• Vacuum (kPag)	-0.2	-0.2	-0.215	-0.22	-0.22	-0.22	0.17	0.17	-0.171	0.17	-0.2	-0.215	0.2		-0.2
	• Pressure (kPag)	0.86	0.86	1.914	0.86	1.72	1.72	1.7	1.7	2.59	0.86	1.7	0.86	0.86		2
	Does the silo have an aeration cone?	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No[1]	No	Yes	No
	Does the silo have aeration pads?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
	Does the silo have impactors?	Yes	Yes	Yes	Yes	Yes	Yes		No	No	No	Yes	Yes	Yes	Yes	Yes
	• Mechanical	X	X	-	-	-	X		-	-	-	-	-	-	-	X
	• Pneumatic	-	-	-	X	X	-		-	-	-	X	X[6]	X	X	-
Rotary Valve	Does the system have a rotary valve?	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
	Is there a gate valve directly below the silo?	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
	Is the gate valve closed during product offload?	-	Yes	No	No	No	No	-	No	-	Yes	No	No	Yes	No	TBD
	How is the gate valve actuated?	-	Solenoid		Manual	Manual	Manual	-	Manual	-	Manual	Pneumatic	Manual	Pneumatic	Manual	Pneumatic
	What size is the rotary valve?	8"	-	7"		10"	10"		6"	-	10"	8"	2 x 6"	8"	8"	18x18

	What is the rotary valve capacity?[6] m^3/hr	5.4	-	1.75	16.6425		15.3		0.1 - 0.51	-	3	6.8				
	What is the clearance of the rotary valve?		-		0.008" - 0.01"	0.003" radial to 0.005"	0.003" radial to 0.005"			-	0.004 - 0.007"					0.012-0.016"
	What material is the valve?	Cast iron body carbon steel rotor	-	Steel	Carbon steel				Carbon Steel	-	Iron / Mild steel					Hard Chrome with Teflon tips
	How often is the rotary valve changed?	> every 7 years	-	~1 year			~ 5 years		Once per year	-	> 3 years	0.5 / yr	1 / year		~7.5 years	
Hopper	Does the system have a lime hopper?	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No	Yes	No[1]	Yes	Yes	Yes
	Does the hopper have a vibrator?	Yes	No	-	Yes	No	No	-	-	Yes	-	No	-	Yes	No	No
	Does the hopper have a vent?	No	No	-	No	Yes	Yes	-	-	No	-	Yes	-	Yes	Yes	Yes
	Does the hopper have air injection?	No	No	-	No	No	No	-	-	No	-	No	-	Yes	No	No
	How is the powder transferred out of the hopper?	Screw Conveyor	Screw Conveyor	-	Screw Conveyor	Screw Conveyor	Screw Conveyor	-	-	Screw Conveyor	-	Screw Conveyor	-	Screw Conveyor	Screw Conveyor	Screw Conveyor
Screw Conveyor	Does the system have a screw conveyor?	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	No[1]	Yes	Yes	Yes
	Does the screw conveyor operate continually?	Yes	Yes	Yes	Yes	No	No	-	-	No	-	Yes	-	Yes	No	Yes
	What type of screw conveyor is used? (e.g. conventional close flight, shaftless conveyor, etc.)	Conventi onal	Conventi onal	Conventi onal Closed Flight	Conventi onal Closed Flight	Conventi onal	Conventi onal	-	-	Conventi onal	-	Conventi onal	-	Conventi onal closed flight	Conventi onal closed flight	Conventi onal closed flight
	What is the capacity of the screw converyor?[6] (m^3/hr)	0.34	0.69		3.20	1.25 - 12.5	15.30	-	-	1.90	-	0.87	-	1.76		
	What material is the screw conveyor?	Stainless	Carbon steel	Steel	Mild steel	Carbon Steel	Carbon Steel	-	-	Carbon Steel	-	304 Stainless Steel	-	316 Stainless Steel		Carbon Steel
	Is your screw conveyor at an angle? (e.g. flat, 20° up, 20° down, etc.)	Flat	Flat	Flat	Flat	Flat	Flat	-	-	Flat	-	Flat	-	Flat	25 degrees up	35 degrees up
	Is there a chute from the screw conveyor to the tank?	No	Yes	Yes	Yes	Yes	Yes	-	-	No	-	Yes	-	Yes	Yes	Goes to LIW feeder
	What is the chute material?	-	Carbon steel	Carbon steel	Carbon steel	Fabric	Rubber	-	-	-	-	Teflon lined	-	Rubber	Rubber	Carbon Steel

	Is there air injected into the chute?	-	No	No	No	No	No	-	-	-	-	No	-	Yes	No	No
	Does the screw conveyor have a sample location?	No	No	Yes	Yes	No	No	-	-	No	-	No	-	No	No	No
	Is the screw conveyor rodable?	No	No	No	No	No	No	-	-	No	-	Yes	-	No	No	No
Slurry Mix Tank	Where does the lime come into the tank?	Top	Top	Top	Top	Top	Top to the side	Top, offset from centre	Top, offset from centre	Top, middle	Top, off centre	Top	Top	Top	Top, above baffle	Top above baffle
Slurry Mix Tank	Where does the water come into the tank?	Top above normal liquid level	Top above normal liquid level	Below liquid level	Top	Top side	Top to the side	Side of the tank, ~ 1m above bottom	Side of the tank below normal liquid level	From the side of the tank	Side of tank, near top	Side injection near top of tank	Side injection near top of tank	Top near side	Top towards edge	Top above baffle
Slurry Mix Tank	Distance between the water inlet and the lime inlet? (m)			1	1	1.7	2.3	1.8	~1.5	1.314	~1	1.053		~1	2	180 degrees apart
Slurry Mix Tank	What kind of level indicator does the tank have?	Guided wave radar	Guided wave radar	Bubble tubes	Bubble tubes	Ultrasonic	Ultrasonic	Ultrasonic	Ultrasonic / radar	Ultrasonic	1 ultrasonic, 1 radar, 1 bubbler	Ultrasonic	Differential pressure	Radar	Ultrasonic	Radar
Slurry Mix Tank	Does the tank have redundant level transmitters?	No	No	Yes	Yes	Yes	No	Yes	Yes		No	No	No	Yes	No	
Slurry Mix Tank	What type of vent is used? (e.g. no vent, vacuum vent)	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Vacuum vent	Open pipe	Open pipe	Vacuum vent	Vacuum vent	Vacuum vent	No Vent	Open pipe
Slurry Mix Tank	What capacity is the vent sized for? (m^3/h)		381		337				168					251	-	
Slurry Mix Tank	What type of scrubber is on the vent?	Wet scrubber	Wet scrubber	Dry scrubber	Wet scrubber	Wet scrubber	Wet scrubber	None	Wet scrubber	None	Wet scrubber	Wet scrubber	None[1]	Wet scrubber	-	None
Slurry Mix Tank	How is the vacuum created (e.g. induced draft fan, air driven venturi, etc.)	Eductor	Eductor	Induced draft fan	Induced draft fan	Induced draft fan	Draft fan (NOT induced)	Induced draft fan	Induced draft fan (not in-line)	-	Natural circulation	Eductor	Eductor	Air driven venturi	-	-
Slurry Mix Tank	Vent fan capacity? (m^3/hr)	167	381		337				168	-		220	170	251	-	-
Slurry Mix Tank	Is there a differential pressure meter on the scrubber?	No	No	Yes	No	No	No	No	No	-	No	No	No	No	-	-
Slurry Mix Tank	Does the vent have baffles?			No	Yes		Yes	No	Yes	-	No	No	No	No	-	-
Slurry Mix Tank	Are the baffles angled?			-	Yes			-	Yes	-	-	-	-	-	-	-

Does the tank have a manhole?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
• Side	X	X	-	X	X	X	X	-	-	X	X	X	X	-	X
• Top	-	-	X	X	-	-	X	X	X	X	X	X	X	X	-
Is the side manhole flush with the internal tank wall?	No	No	-	No	No	No	No	-	-	No	Yes	Yes	No	-	Yes
Does the tank have baffles?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No[1]	Yes	Yes	Yes
What is the agitator RPM?			370	100	218	170		100	1725	350	350	350	87	226	125
What is the agitator horsepower?	1		3	3	10	10	2	2	1.5	1	2	1	5	3	10
How many impellers does the agitator have?	1	1	3	1	2	2	4	4	2	1 impeller, 3 blades	1	1	2	3	4
What size is the agitator impeller(s)? (mm)	305	305	419	813		686		605	384	384	356	384	Bottom: 635 Radial Top: 762 Pitch	546	838
What is the agitator impeller type?			Maxflo	4HP45 High Efficiency pitched turbine blade	Sloped blade	Angled Blades (4 blades)		Pitched blade (45 degrees)	Lightnin A310 axial flow impeller	A 310	Marine	Wedge shaped lightnin	Dyamix - Model GMX3-21-5		A-200
In what direction does the agitator mix the slurry?					Clockwise	Clockwise rotation			Clockwise				Top - towards bottom Bottom - towards side		
• Toward the bottom?	X	X	X	X				X		X	X	X	-	X	
• Toward the top?	-	-	-	-				-		-	-	-	-	-	
Distance from the liquid level to the impeller(s)? (m)	0.478	0.478	0.5		1.524 2.946			0.5 - 0.75	Batch operation	1.1				0.5	
Is the agitator vertical or inclined?	Vertical	Vertical	Vertical	Vertical	Vertical	Vertical		Inclined	Inclined	Vertical	Vertical	Inclined[2]	Vertical	Vertical	Vertical
How often must solids buildup be removed from the wall?	Once a week	Once a week	~ 6 months	> 1.5 years	6 - 12 months	~12 months	4 weeks	~12 weeks	8 weeks	~14 weeks	1/yr	2/yr	2 - 3 months	Never	

	If there is solids buildup, is it caused by splashing, high humidity and dust, or all?	All		None	None	All	All	All	All	All	All	High humidity / dust	High humidity / dust	All	High humidity / dust	
	What are the slurry tank dimensions? (dia x height) (m)	1.37 x 1.37	1.37 x 1.37	1.83	2.44 x 2.44	3.96 x 3.66	3.96 x 3.66	1.8 x 2.1	1.8 x 2.1	1.74 x 2.140	1.8 x 1.8	1.8 x 1.95	1.8 x 1.9	2.1 x 2.4	2.4 x 2.4	2.8 x 3.1
	Tank volume (m^3)	2.0	2.0	6.4	11.4	45.1	45.1	5.3	5.3	5.1	4.6	5.0	4.8	8.3	10.9	19.1
	Normal liquid level in the tank (From the bottom)? (m)	0.73	0.73	65%	1.46	2.2	2.5	1.55	1.5	Batch operation	1.3	1.4	1.0	1.3	2.1	2.7
	What is the residence time for lime in the tank? (from mix tank to injection point) (mins)		7.8	30	30	72	240	Dec-15	20 - 30	18	~ 20			30 - 40	360	13
	Is slurry aid added to the tank?	No	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No
	Where is the slurry aid inlet located?	-	-	-	-	Top of slurry tank	-	-	-	-	-	-	-	-	-	-
Feed Pump	What material is the pump suction line?	Teflon	Carbon steel	Flexible Hose (kemflex)	Flexible Hose (kemflex)	FRP	FRP	Flexible hose	Flexible hose	Flex hose	Carbon steel	Carbon steel	Carbon steel	Carbon steel and flexible hose	Carbon steel	Carbon steel A333
Feed Pump	What type of pump is the feed pump? (e.g. centrifugal end suction, centrifugal inline, etc.)	Centrifugal (Inline vertical pump)	Centrifugal (Wilfey)		Centrifugal	Centrifugal side suction	Centrifugal side suction	Centrifugal side suction slurry pump	Wilfley K-Pro slurry pump	Centrifugal end suction top discharge	Centrifugal	Centrifugal	Centrifugal	Wilfley - A7, centrifugal end suction	Centrifugal end suction	Centrifugal end suction
Feed Pump	Continuous or intermittent pump?	Cont.	Cont.	Cont.	Cont.	Int.	Int.	Cont.	Cont.	Cont.	Int.	Cont.	Cont.	Cont.	Cont.	Cont.
Feed Pump	Is the pump on a VFD?	Yes	Yes	No	Yes	No	No	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Feed Pump	Does the pump have permanent water flush lines?	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	Yes	No	Yes
Feed Pump	If it is a batch process is there a pump flush procedure?	-	-	-	-	Yes	Yes	-	-	No	Yes	-	-	-	No	-
Feed Pump	It it's a continuous process is there an automatic flush?			No	No	Manual	Manual	No	No	No	-	Manual	-	No	No	No
Feed Pump	What it the flush frequency and duration?			-	Every 12 hours by CRO	As required	As required	-	-	Not routinely flushed	Weekly as needed		-	As needed	-	-

Slurry Transfer Lines & Recycle Line	Do you have a recirculation line in your system?	No	No	No	No	Yes	Yes	Yes	No	Yes	Yes (not used)	Yes (not used)	Yes (not used)	No	Yes	Yes
	Is there slurry aid added to the transfer lines?	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
	Where is the slurry aid added?	-	-	-	-	-[5]	-	-	-	-	-	-	-	-	-	-
	Does the slurry in the recirculation line flow through the line continuously?	-	-	-	-	No	Yes	Yes	-	Yes	No	-	-	-	Yes	Yes
	What is the percent grade of the slope of the recirculation line sloped back into the slurry mix tank?	-	-	-	-	Uphill in some sections			-	0	0 - 1%	-	-	-	Not sloped	1%
	What is the material of the pipe?	Fire hose	Fire hose		Carbon steel	FRP	FRP	Carbon Steel	Carbon Steel	Carbon steel ASTM A106B, SMLW	Carbon steel	A106-B CS	Carbon steel	Carbon steel and flexible hose	Carbon steel	Carbon steel A106
	What is the size of the pipe?	1.5"	1.5"	2"	2"	4"	4"	3" reduced to 2"	3"	Suction: 2-1/2", Discharge & recirculation: 2" Sch 80	3" pump suction 2" pump discharge / recirc	2"	2"	1.5"	2"	3" NPS
	What type of valves are used?	Plug valves	Plug valves	Ball	Ball	Diaphragm	Diaphragm and plug valves	Gate and plug	Knife gate	Knife gate	Pinch	Knife gate	Knife gate	Pinch	PV	Plug valves
	What size of valves are used?	3" and 2"	3" and 2"	2"	2"	3"	3"	3"	3"	Per line size	Per line size	2"	2"	1.5"	2"	3"
	What is the slurry velocity? (m/s)					~1.5	0.7 - 1.5	1.08	0.7	Suction: 1.6 Discharge: 2.7	0.6 - 1.5	2.5	2.5	1.5 - 2.0	3.7	2.2
	How is the flow rate measured?			Tank make up output	Flow meter	-	-	Magmeter	Inline magnetic flow meters	Flow meter	Mag meter	Mag meter	Mag meter	Magnetic flowmeter	Flow meter	Pressure control

	How is the flow rate controlled?	Pump - manual VFD	Pump - manual VFD	Throttling discharge valves	VFD on pump	Makeup water to slurry tank	Makeup water to slurry tank	Feedback to pump VFD	Feedback control from flowmeter to pump VFD	WLS pH	Manual control valve	Tank level	Tank level	VFD on pump	Solenoid FV	Control valve
Slurry Concentration and Dosing	What is the slurry concentration goal?	None	None			5 % - 10%	5 % - 10%	2.5 - 3% wt, 10 – 12% vol	3-5 v/v%	5 - 10 wt%	~ 5% vol (1-2% wt) not critical	None	None		1.1 g/cm3	10% wt
	What determines how much lime is added to the softener?	Total flow to HLS	Total flow to HLS	pH, Hardness, Alkalinity	HLS ALK + pH w/ the inlet flow rate into the HLS	pH and soluble hardness effluent	pH and soluble hardness effluent	Effluent pH	WLS pH, effluent hardness	WLS pH	WLS pH	HLS pH	HLS pH	HLS pH	Hardness of the treated water leaving HLS	WLS flow rate and WLS pH meter
	How is the slurry concentration measured or ensured?	Not measured	Not measured	Not measured	Not measured	Manual settling test	Manual settling test	Graduated cylinder v/v% pour test	Manual settling test	Manual settling test	Manual settling test	Cone test (manual)	Cone test (manual)	Manual test	Ensured by weight of lime and volume of slurry	Ratio with fresh water inlet to slurry tank from LIW feeder
	How is slurry concentration measured in line?	-	-	-	-	-	-	-	-	-	-	Vol. feeder dry product rate / BFW rate (Microwave dry product backup)	Rotary valve dry product equiv. rate / BFW rate	-	-	-
	Is the lime dosed based on volume or weight?	Weight	Volume	Volume	Volume	Volume	Volume	Volume	Volume	Volume	Volume	Weight	Weight	Volume	Weight	Weight
	What system component is used to dose the lime?															
	• Rotary valve			X		X		X	X		X		X[3]			
	• Loss and weight hopper	X			X										X	X
	• Screw conveyor		X				X			X		X		X		

Notes:

1. To be added
2. To be changed to vertical
3. To be changed to volumetric feeder
4. Information on this facility was collected however the facility is not operational
5. Slurry aid is added to the slurry tank
6. To be removed
7. Where capacity is calculated based on weight density is assumed to be 400 kg/m3
8. Shaded cell indicates information that was not supplied by participants