

Hydrated lime handling systems for thermal enhanced oil recovery: Toolkit

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1.0 Introduction

High calcium hydrated lime ($\text{Ca}(\text{OH})_2$) 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.

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 presented an opportunity to 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.

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 handling system with the MgO guidelines as a starting point.

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 handling 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.

A second report, *Hydrated lime handling systems for thermal enhanced oil recovery: Guideline development report*, provides background, methodology, and analysis undertaken to develop the design and operational and maintenance guidelines. It is a resource for operators wishing to develop a greater understanding of the systems, their potential challenges, and how they can be addressed. This second report can be openly accessed via www.albertawatersmart.com/featured-projects/best-practice-guidelines.html

2.0 Background

2.1 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.

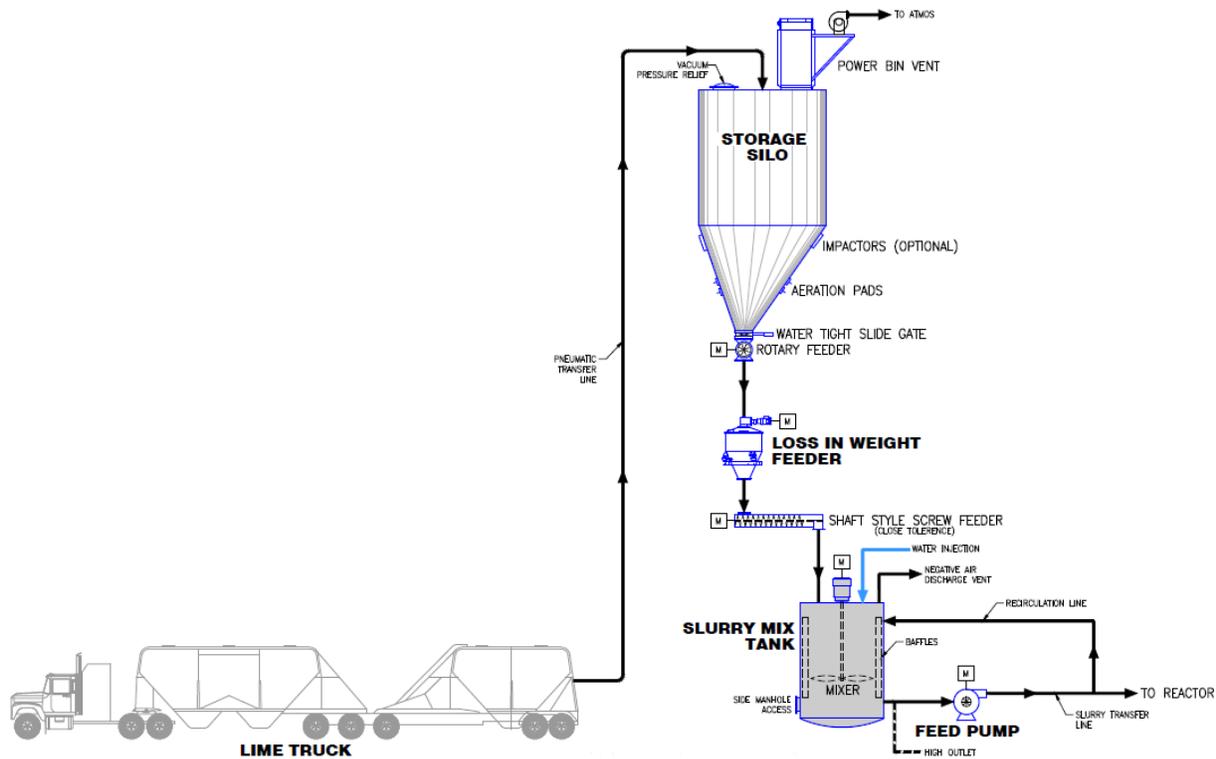


Figure 1 – Typical lime handling system (diagram provided by Graymont Western Canada Inc.)

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 17m³/min (600 cfm) to 24 m³/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

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.

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.

2.2 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.

2.3 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, $\text{Ca}(\text{OH})_2$, 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 $\text{Ca}(\text{OH})_2$ enters solution and dissociates, allowing further neutralizing reactions. The solution pH is increased through the introduction of $\text{Ca}(\text{OH})_2$. 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 $\text{Ca}(\text{OH})_2$ particles. The process by which $\text{Ca}(\text{OH})_2$ is produced dictates material coarseness and is therefore manufacturer dependent.

3.0 Supply chain guidelines

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	<ul style="list-style-type: none"> Develops specifications and provides to EPC
Engineering, Procurement, Construction (EPC) company (e.g., Vista Projects)	<ul style="list-style-type: none"> Design based on owner specifications, including: <ul style="list-style-type: none"> mixing chemistry control philosophy and dosing system 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)	<ul style="list-style-type: none"> 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)	<ul style="list-style-type: none"> Provides specific components based on direction from Equipment Package Supplier
Lime supplier (e.g. Graymont)	<ul style="list-style-type: none"> Develops the powder from raw materials, and provides the product at specification to the owner
Independent lime transporter (via trucks)	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Quality assurance testing of product when it arrives on site Conducting operations and maintenance of the lime handling systems

Stakeholder	Roles and responsibilities
Owner/Operator	<ul style="list-style-type: none"> Undertakes preventative and as-needed maintenance on lime handling systems Corresponds with the lime Transporter, lime supplier, EPC and Equipment Package supplier, as required to undertake troubleshooting

4.0 Design guidelines

The proposed design guidelines are representative of the key challenges experiences by hydrated lime system operators. The proposed guidelines reflect the solutions identified collectively between operators, designers, product and equipment suppliers, and Alberta WaterSMART.

4.1 Lime storage silo

4.1.1 Level measurements

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.

4.1.2 Dust control

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 17m³/min (600 cfm) to 24 m³/min (850 cfm).

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).

4.1.3 Flow promotion

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.

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.

4.1.4 Moisture control

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.

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

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.

Proposed design guideline:

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

Proposed design guideline:

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.

4.2.1 Rotary valve

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.

4.2.2 Hopper

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.

4.2.3 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.

4.2.4 Chute to the slurry mix tank

Proposed design guideline:

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.

Proposed design guideline:

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

4.3 Lime handling system dosing and concentration control

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 2 for a comparison of different lime powder volume control components.

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.

Proposed design guideline:

D17. It is recommended that a hopper is included as a component in the powder transfer and lime dosing system. Table 2 offers a comparison between lime dosing strategies.

Table 2 – Comparison of lime dosing strategies

Component responsible for lime powder dosing	Advantages	Disadvantages
Only rotary valve	<ul style="list-style-type: none"> • Fewer components to maintain • Fewer components to have issues with • Less up front capital cost 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Fewer components to maintain • Less up front capital cost 	<ul style="list-style-type: none"> • System is prone to flow through • Less accurate volumetric control of lime dosing
Loss in weight hopper ¹	<ul style="list-style-type: none"> • More accurate lime dosing control ($\pm 1\%$ by weight) (National Lime Association, 1995) • Newer loss-in-weight hoppers have a user friendly interface 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Less expensive than a loss in weight hopper • Less maintenance required than with a loss-in-weight hopper 	<ul style="list-style-type: none"> • 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.

4.4 Slurry mix tank

4.4.1 Tank sizing and material

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.

4.4.2 Slurry mix tank venting and dust control

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.

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.

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.

Proposed design guideline:

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

Proposed design guideline:

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).

Proposed design guideline:

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.

Proposed design guideline:

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).

4.4.3 Slurry tank baffles

Proposed design guideline:

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.

Proposed design guideline:

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.

4.4.4 Slurry tank agitator and mixing

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.

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.

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.

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 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.

4.4.5 Slurry tank level measurement**Proposed design guideline:**

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

Proposed design guideline:

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.

4.4.6 Slurry tank inlets and outlets

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.

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.

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.

4.5 Slurry transfer lines and feed pump

Proposed design guideline:

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

Proposed design guideline:

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.

Proposed design guideline:

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.

4.5.1 Lines**Proposed design guideline:**

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.

Proposed design guideline:

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.

Proposed design guideline:

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.

Proposed design guideline:

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.

Proposed design guideline:

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.

Proposed design guideline:

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.

Proposed design guideline:

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.

Proposed design guideline:

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.

4.5.2 Valves

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 design guideline:

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

Proposed design guideline:

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

Proposed design guideline:

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

Proposed design guideline:

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.

4.5.3 Pumps

Proposed design guideline:

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.

Proposed design guideline:

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.

Proposed design guideline:

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.

4.6 Water quality and temperature

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 2.

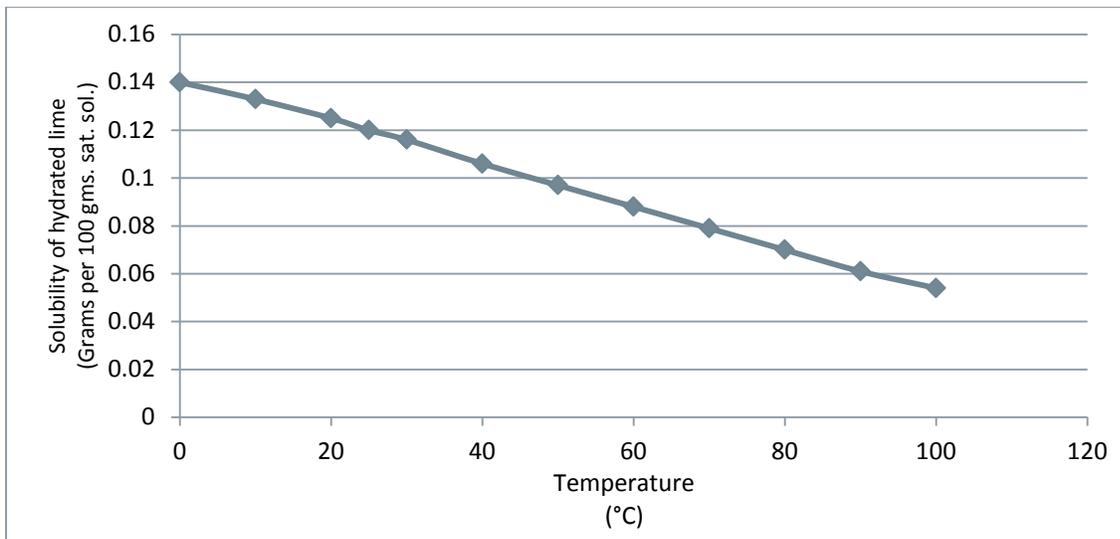


Figure 2 – Solubility of lime with increasing water temperature (National Lime Association)

Proposed design guideline:

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.

Proposed design guideline:

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.

5.0 Operational and maintenance guidelines

The proposed operational and maintenance guidelines were developed based on the key challenges identified by operators of existing systems. The guidelines do not represent an exhaustive list of all necessary operation and maintenance procedures for these systems.

Some of the proposed guidelines are presented with a minimum timing surrounding maintenance guidelines, the timing may require adaptation by operators and owners based on the unique characteristics of each system.

5.1 Lime storage silo

5.1.1 Level measurement

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.

5.1.2 Dust collection

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.

5.1.3 Flow promoters

Proposed operational and maintenance guideline:

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.

Proposed operational and maintenance guideline:

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.

Proposed operational and maintenance guideline:

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.

5.1.4 Moisture control

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.

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

5.2.1 Rotary valve

Proposed operational and maintenance guideline:

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

5.2.2 Hopper

Proposed operational and maintenance guideline:

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

5.2.3 Chute to slurry mix tank

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.

5.3 Lime handling system dosing and concentration control

5.3.1 Lime dosing and transfer system

Proposed operation and maintenance guideline:

O10. If a rotary valve is used as 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.

5.3.2 Slurry dosing and control system

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.

5.4 Slurry mix tank

5.4.1 Slurry mix tank venting and dust control

Proposed operation and maintenance guideline:

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.

Proposed operation and maintenance guideline:

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.

Proposed operation and maintenance guideline:

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

5.4.2 Slurry tank baffles

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.

5.4.3 Slurry tank agitator and mixing

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.

5.4.4 Slurry tank level measurement

Proposed operation and maintenance guideline:

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

5.5 Slurry transfer lines and feed pump

5.5.1 Valves

Proposed operation and maintenance guideline:

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.

Proposed operation and maintenance guideline:

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

5.5.2 Pumps

Proposed operation and maintenance guideline:

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

Proposed operation and maintenance guideline:

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.

5.6 Lime handling system preventative maintenance

It is important for facilities to have a preventative maintenance schedule and it is suggested Table 3 should be used as a starting point to be adapted to each facility's needs.

Table 3 – 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 as 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

6.0 References

National Lime Association. 1995. *Lime –Handling, Application and Storage*. Arlington, Va.

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).

WaterSMART. 2014. Magnesium oxide (MgO) dosing systems for thermal enhanced oil recovery. (online). Retrieved from: <http://albertawatersmart.com/featured-projects/best-practice-guidelines.html> (Accessed 21 June 2016).