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Magnesium Oxide (MgO) Dosing System Design, Operation and Maintenance, and Supply Chain Guidelines for Thermal Enhanced Oil Recovery

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Prepared by Alberta WaterSMART

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Foreward

MgO is used to remove silica from process water (produced water and makeup water), as one component of a process to meet requirements for boiler feed water quality. Approximately 40 MgO slurry systems are operating in thermal enhanced oil recovery facilities in Alberta. These facilities were commissioned over several decades from the 1980s to present day and their operation and maintenance presents numerous challenges to the facility operators.

Until now, operators have managed system challenges on an individual basis with their equipment suppliers and engineering consultants. However, many of system challenges occur for most facility operators. This situation presented an opportunity to share knowledge within the industry on potential mitigation options to address challenges with current systems, and to develop guidelines for system design, operation and maintenance that will improve the design and management in new systems.

These guidelines draw on information from the report “Magnesium Oxide (MgO) Dosing Systems for Thermal Enhanced Oil Recovery, Guideline Development Report” and can be used as a quick reference for operators in developing specifications and standard operating practices (SOPs). The development of these guidelines was made possible through sponsorship by Veolia Water Solutions and Technologies, facilitated and developed by Alberta WaterSMART Solutions Ltd. (Alberta WaterSMART). Input was collected from 10 industry companies, an MgO powder supplier, and an MgO equipment supplier.

“Magnesium Oxide (MgO) Dosing Systems for Thermal Enhanced Oil Recovery, Guideline Development Report” provides the background, methodology and analysis undertaken to develop the design and operation 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; and to explain how and why these guidelines were developed.

The main observation from developing these guidelines is the significant impact that suppliers and consultants have 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 that 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 creates a situation where suppliers provide the lowest cost design that allows them to win the contract. If agitator or tank specifications are not detailed enough, the supply chain process may not provide the most efficient or effective equipment. Thus, the primary recommendation is for owners to use the guidelines proposed in this report to develop their own specifications for MgO systems.

Another major consideration is the understanding of MgO slaking chemistry. A number of challenges are associated with the use of MgO, however, one of the key challenges is the buildup of solids and scale on equipment and in transfer lines. One of the major factors contributing to this challenge is the reaction of MgO with water to form a solid deposit. In addition to plugging many pieces of equipment, these solids can also fall off the tank walls to collect on the bottom of the tank or transfer lines.

This document provides an overview of the MgO system, a review of MgO chemistry, and the MgO guidelines.

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1 System Overview

MgO is used in thermal enhanced oil recovery facilities to remove silica from process water (produced water and makeup water) as one component of a process to meet requirements for boiler feed water quality. The MgO is used in a powder form and is mixed with makeup water onsite to produce a slurry. The slurry and the process water are combined in a warm or hot lime softener or an evaporator to remove silica. In this report the warm or hot lime softener or evaporator is referred to as the reactor.

MgO 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:

- MgO Powder Storage Silo
- Rotary Transfer Valve
- MgO Hopper
- Screw Conveyor
- Slurry Mix Tank
- Feed Pump

Figure 1 shows a schematic of the common configuration of an MgO slurry system.

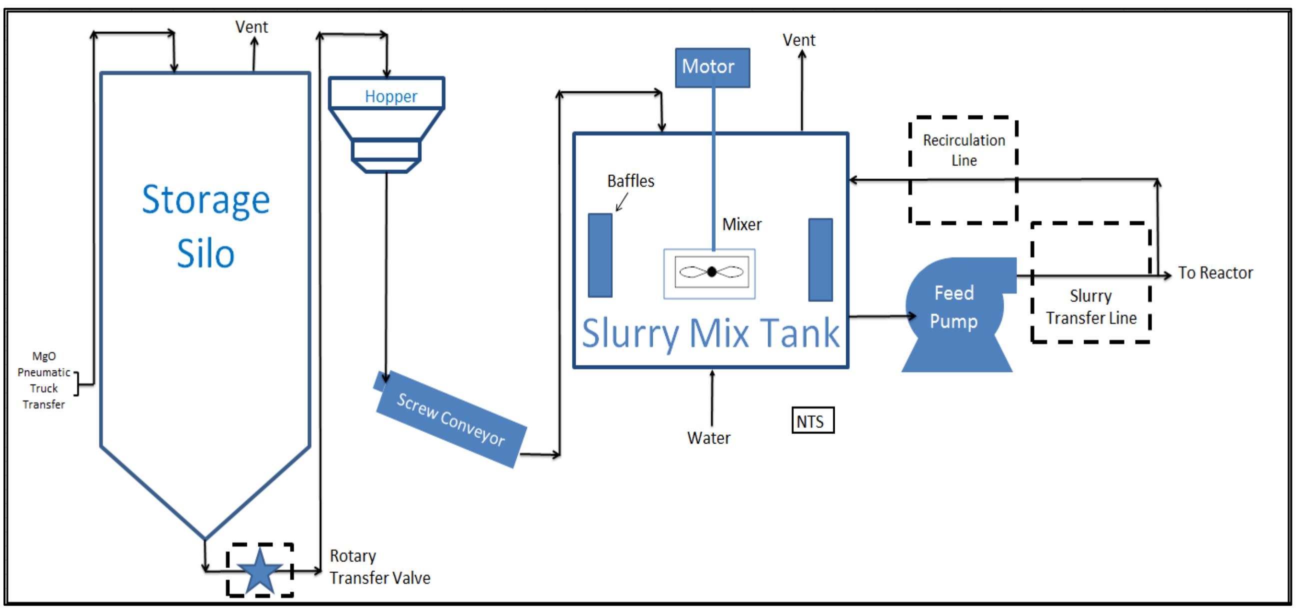

Figure 1. MgO Slurry System

The MgO powder is delivered to the facility by an MgO powder supply truck and is transferred from the truck to the storage silo pneumatically. The silo is typically located above the slurry mix tank and has, at a minimum, a filter and a level transmitter. Flow out of the silo is encouraged by either a physical vibration or shaking system, and/or the introduction of air into the bottom of the silo.

The powder is transferred from the silo to the slurry mix tank using either a loss-in-weight or a volumetric transfer control approach. Typically, a hopper sits between the storage silo and the slurry mix tank. 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 MgO product slurry tank dosing. Where hoppers are used as the dosing device, they are followed by a screw conveyor.

Where hoppers are not used, volumetric transfer systems include a screw conveyor and may also include a rotary transfer valve. Rotary valves and screw conveyors may be used as the MgO product slurry tank dosing control and measurement system.

The transfer device feeds the product to the slurry mix tank through a chute. In the slurry mix tank, makeup water is mixed with the MgO 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 and a level transmitter.

The slurry is transferred from the mix tank by a feed pump, through slurry transfer pipelines to the downstream reactor. Recirculation piping have also been used to recirculate the slurry back into the slurry mix tank.

2 MgO Chemistry

Upon contact with water, magnesium oxide (MgO) begins to hydrate to form magnesium hydroxide ($Mg(OH)_2$) via the following exothermic reaction:

$$MgO + H_2O \rightarrow Mg(OH)_2$$

The degree to which this hydration reaction occurs depends primarily on the temperature of the mix-water and the slurry density (% solids). The effect of temperature on hydration can be seen in Figure 2, where the percent hydration is shown for 6% MgO slurry in water.

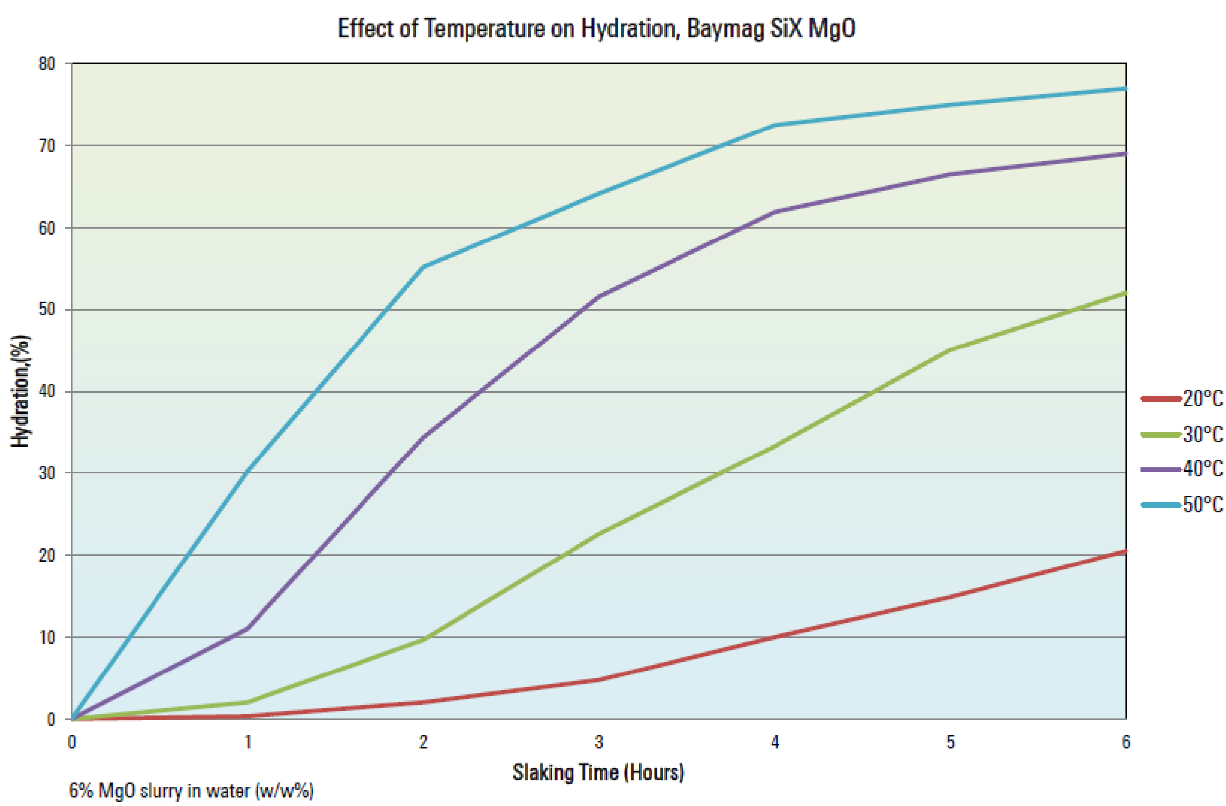

Figure 2. Baymag SiX MgO slaking curve

Silica removal is significantly more efficient when the MgO is maintained as MgO in the slurry and is not allowed to hydrate. The conversion of MgO to $Mg(OH)_2$ must occur within the reactor to ensure maximum surface area for silica adsorption and subsequent removal.

A number of challenges are associated with the use of MgO, namely the buildup of solids and scale on equipment and in transfer lines. One of the major factors that influences this is the reaction of MgO with water to form a solid deposit.

MgO is hydroscopic, which means it readily absorbs and retains moisture. Any exposure to moisture causes the MgO powder to buildup on equipment such as the slurry tank internal walls and any internal tank equipment, where it may eventually fall off and accumulate at the bottom of the slurry tank. Excessive buildup of solids in the bottom of slurry tank may plug suction lines, feed pumps and discharge lines.

In addition, if the slurry makeup water is highly alkaline (such as untreated utility waters), it can react with the slurry to form calcium carbonate scale in the feed system piping.

Figure 2 shows the slaking efficiency, or percent hydration, for the Baymag SiX magnesium oxide at 6% MgO concentration at various times and temperatures. For the most efficient silica removal, the hydration, or slaking, reaction should not occur in the slurry tank and transfer lines but should occur after the slurry reaches the downstream reactor. Therefore, as illustrated in Figure 2, the magnesium oxide feed system should be designed with low retention times and low makeup water temperatures.

Guidelines related to retention times and temperatures are provided in the appropriate sections of this report.

3 Supply Chain Guidelines

Although the MgO 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 its 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, or stakeholders, in the design process and operating 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 that 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 creates a situation where suppliers provide the lowest cost design that allows them to win the contract. If agitator or tank specifications are not detailed enough, the supply chain process may not provide the most efficient or effective equipment.

Thus, 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 guidelines to develop their own requirements specific to MgO systems.

Table 1. MgO system value chain

Stakeholder	Roles and Responsibilities
Facility Owner	• Develops specifications and provides to EPC

Engineering, Procurement, Construction (EPC) company (e.g., Bantrel)	• Design based on owner specifications, including:
	  ○ 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 MgO 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
MgO supplier (e.g., Baymag)	• Develops the powder from raw materials, and provides the product at specification to the owner
Independent MgO transporter (via trucks)	• Loads, transports, and off-loads MgO from trucks for delivery to the facility • Responsible for ensuring on-spec MgO 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 MgO systems • Undertakes preventative and as-needed maintenance on MgO systems. • Corresponds with the MgO Transporter, MgO supplier, EPC and Equipment Package supplier, as required to undertake troubleshooting

4 Design Guidelines

The guidelines in the section are representative of the key challenges experienced by existing MgO system operators, and solutions identified collectively between operators, designers, product and equipment suppliers, and Alberta WaterSMART.

4.1 Storage Silo

1. Use the level measurement device in the silo for inventory control only, and do not use it as a means for dosing measurement to the slurry tank. Challenges associated with attaining a high level of accuracy with these devices will likely cause ongoing system operating and performance issues that could otherwise be avoided.

2. The best success with level measurement has been with radar devices. The performance of guided wave radar is sensitive to how the transmitter and cable are installed and the location of the sensor mounting nozzle in the silo must conform to the instrument manufacturer's requirements. The presence of dust and dusty buildup reduces the accuracy of ultrasonic level measurement devices.

3. Size the silo vent to at least match:
    - the pneumatic air transfer flow expected for pneumatic product transfer into the silo, and
    - air injection (aeration pad/aeration cone).

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

5. Include a means of air injection (aeration pads/aeration cone) into the silo to avoid bridging of the silo by enhancing the flow behaviour of the MgO product.

4.2 MgO Transfer from Silo to Slurry Mix Tank

6. A fully redundant system downstream of the silo will avoid system shut-downs when operational challenges occur throughout the system, and increase efficiency of the system while it operates.

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

4.2.1 Rotary Valves

Based on the critical challenges created by using the rotary valve as the primary source of volumetric control for the system it is recommended that this type of process control is not used. This is addressed in Design Guidelines 8 and 9.

4.2.2 Hopper

8. Use a hopper for flow control of powder from the silo to the slurry tank. Load cells or level control devices have been used to measure flow into the hopper. There is no clear evidence demonstrating which is better. Additional investigation into level detection is recommended. Do not use a rotary valve as the sole method of MgO powder volume control.

Table 2. Advantages and disadvantages of loss-in-weight and volumetric hoppers

Loss-in-weight		Volumetric	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
More accurate MgO volume control	More expensive	Less expensive	Less accurate MgO volume control
Newer loss-in-weight hoppers have a user friendly interface	Area must remain dust free, and/or device cleaned regularly (more maintenance required than a volumetric hopper)	Less maintenance required than with a loss-in-weight hopper	Plugging of level switched creates inconsistent process control
	Older models are difficult to operate		

9. Use a rotary valve or slide gate for filling the hopper and a screw conveyor to transfer powder from the hopper to the tank.

10. 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 product feed into the hopper. It should not be an open hole, and should include a dust sock or scrubber to prevent dust in the work area.

11. Include a form of air injection into the hopper to prevent plugging and level control challenges in the hopper.

4.2.3 Screw Conveyor

12. Include an air purge into the end of the screw conveyor or after the screw conveyor to prevent moisture and product buildup in the MgO powder transfer system and to facilitate tank venting.

13. 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 vapour into the conveyor.

14. If the MgO powder is batched into the slurry mix tank, an automated valve should be installed to isolate the screw conveyor from the tank while it is not operating. This will prevent excess moisture from entering the conveyor.

4.2.4 Chute

15. Construct the chute from flexible material, such as an absorbent fabric, rubber, or neoprene material to prevent accumulation of material on the walls and allow for easier cleanout. Although the installation of an air purge at the end of the screw conveyor is the best option to prevent plugging in the screw conveyor, a chute downstream of the screw conveyor constructed of absorbent material is an alternative option. This also allows dry air flow through the fabric to contribute to proper venting of the slurry mix tank. Include a clean-out on the chute where it is made of hard pipe, to provide access to detach solids formation buildup in the chute.

4.3 Slurry Mix Tank

4.3.1 Solids Buildup

16. Slurry mixing modelling should be undertaken to ensure adequate mixing of the slurry in the tank, considering all appropriate variables relating to the tank geometry and baffles, and water temperature.

17. Minimize the MgO hydration before the reactor to 13%. MgO hydration is determined based on Figure 2. Percent hydration will be reduced by the following factors:
    - Low retention time (impacted by physical design parameters such as tank size and recirculation); and
    - Low water temperature.

18. If the ratio of the impeller to tank diameter is 1/3 to 1/2 ideal impeller speeds are between 60 and 150 RPM to prevent splashing causing product buildup on the slurry tank walls. For all impeller to tank ratios the impeller speed should be a maximum of 350. See Figure 3 as a guideline for the appropriate impeller speed associated with different impeller: tank diameter ratios. Note that all mixing variables must be considered together to ensure adequate mixing.

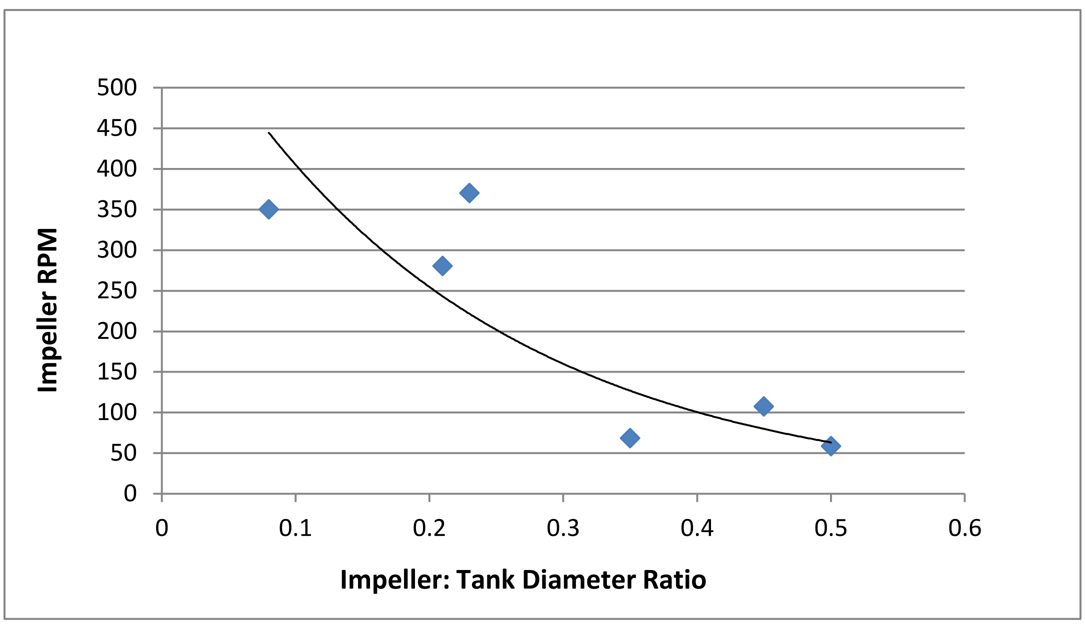

Figure 3. Design curve for impeller to tank diameter ratio to impeller RPM

19. Locate the water inlet below normal liquid level to prevent solids buildup in the tank.

20. In addition to proposed Design Guideline 18, the slurry agitator should enter the tank from the top, parallel to tank walls, to decrease the potential for splashing, causing solids buildup. This will also promote effective mixing. The slurry agitator impellers should be below the normal liquid level.

21. Do not use recirculation lines unless site specific design parameters require them. Recirculation lines are strongly correlated with solids buildup in the slurry tank.

4.3.2 Tank Sizing

See proposed Design Guideline 17.

4.3.3 Dust Control and Tank Venting

22. Include an active slurry tank vent system on the slurry mix tank to mitigate dust issues and to control moisture upstream of the slurry mix tank. See guidelines 24 to 26 for tank vent system design.

23. 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.

24. Locate the slurry mix tank vent as far away as practical from the MgO powder inlet, as the vent will suck up the powder and plugging will occur more quickly.

25. Include 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.

26. The vent system should include a wet scrubber. It should operate under negative pressure and vent outside.

4.3.4 Baffles

27. Include four baffles in the slurry mix tank to promote effective mixing. Baffles should be no higher than the high liquid level.

28. 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.

4.3.5 Agitator and Mixing

29. Size the agitator impeller diameter to be 1/3 to 1/2 of the tank diameter.

30. Use redundant level measurement in the slurry mix tank, with two different methods of level measurement. The ultrasonic level measurement device has a lower chance of plugging compared to other devices. There are challenges associated with each level measurement device:
    - Bubble tubes
        - 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 caked with material and require maintenance.
        - Both cable and cone types can be affected by dust particulate, creating inaccurate readings.
    - Ultrasonic
        - The presence of foam creates inaccurate readings.

31. Dust can create challenges with level measurement due to buildup on level measurement devices and false reading due to particulate; see proposed Design Guideline 24 regarding dust control.

4.3.6 MgO Inlet to Slurry Mix Tank

32. MgO powder should be added to the tank as close to the centre of the tank as possible.

33. MgO powder inlet should not enter directly over top of the baffles or agitator to avoid product build up.

4.3.7 Slurry Outlet from Slurry Mix Tank

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

4.4 Transfer Lines

35. Create a pipeline specification specifically for the MgO system including smooth walled hose and Victaulic style couplings.

36. Minimize slurry transfer line length and elbows to prevent plugging. Where elbows are necessary use long radius elbows.

4.4.1 Lines

37. To control transfer pipe plugging due to settling, ensure the slurry velocity is greater than 2.5 m/s. High velocities have shown a strong correlation with reduced plugging. Ensure that the proper hydraulic calculations surrounding settling velocity are completed. Higher velocities will require higher pressures to overcome losses and therefore will require more expensive equipment. This should be considered in making decisions on pump and pipeline design.

38. Use smooth walled hose for slurry transfer lines to provide easy maintenance, and/or replacement. At a minimum, use hose in the pump suction line between the slurry mix tank and the pump.

39. Avoid reduced pipe diameter sections and instrumentation or control on the lines to prevent solids buildup and plugging in these locations.

40. Use VFDs over control valves for slurry dosing control to reduce potential control valve erosion and slurry control issues.

41. Ensure pump VFDs for modifying slurry strength do not allow velocities to fall below the design minimum of 2.5 m/s, to prevent line plugging.

4.4.2 Valves

42. Do not use pinch valves for control valves on slurry lines, as they are easily eroded and fail.

43. If recirculation lines must be used place recirculation line valve at a system high point in the system, and as close to the reactor as possible.

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

4.4.3 Feed Pump(s)

45. Include permanent water flush lines upstream of the pumps and a water flush procedure to be operated after the pump is used, every time.

46. Design to allow isolation and flushing of backup pumps before and after use.

4.5 Water Quality and Temperature

See proposed Design Guideline 17.

47. The MgO slurry tank should be treated as a reactor in terms of water quality and chemical interactions. The pH in the tank is typically above 9. All water quality characteristics should be considered to reduce scaling of equipment. Increased impurities will increase scaling challenges.
48. Minimize water temperature; 25°C is an ideal water temperature and a maximum suggested water temperature is 40°C.

4.6 Dosing and Slurry Concentration Control

49. A loss-in-weight hopper and a screw conveyor to control the MgO dosing ensures accuracy and decreases incidents of downstream reactor upsets. See Design Guideline 9.

50. Use an alarm system on the transfer from the silo to the hopper or from the hopper to the slurry tank to detect interruption of powder transfer.

5 Operational and Maintenance Guidelines

The following operation and maintenance guidelines were developed based on some of the key challenges identified by operators of existing systems. Therefore, they do not represent an exhaustive list of all necessary operation and maintenance procedures for these systems, but the most critical considerations to ensure efficient operation.

Many of these guidelines are presented with a minimum maintenance guideline based existing operator input, and will require adapative management by operators and owners based on the unique characteristics of each system.

5.1 Storage Silo

1. Undertake scheduled preventative maintenance on the silo measurement device at least once every three months. Operators should adapt this schedule as required for their system.

2. Perform preventative maintenance on the silo vent filter a minimum of once every three months or approximately every 10 offloads whichever comes first.

3. Minimize pneumatic transfer pressure of MgO from the truck to the silo to the pressure required for transfer. This has shown improvements in dust control at existing facilities.

4. To prevent moisture from entering the silo and creating level measurement and silo clogging challenges, ensure 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 (i.e., PVRVs).

5. Do not use physical flow promoters (vibrators, impactors, etc.) while the silo is being loaded with product. This promotes compaction of the product in the silo, which may promote clogging and inconsistent feed rate.

6. Caution should be taken not to introduce too much air, which may cause product control challenges for control devices. Limit the amount of air introduced to the silo to what is required to ensure flow out of the tank.

5.2 MgO Transfer from Silo to Slurry Mix Tank

No operation and maintenance guidelines have been developed specific to hoppers. However, similar to the slurry tank vent, although less critical, the hopper vent should continually operate and be included in scheduled maintenance.

The screw conveyor is typically difficult to clean due to its design. To reduce plugging in the screw conveyor, operators have reported manually knocking the conveyor to help dislodge the product from the inside walls. Alternatively, operators knock a rod inside the screw conveyor for the same affect if a hatch or cleanout is available. However, no specific guidelines are proposed for maintenance of the screw conveyors.

7. If chute plugging issues have been a concern, implement preventative maintenance on the chute to prevent large formation buildup in the chute. Maintenance can be reduced by:
   - Minimizing water temperature
   - Ensuring proper slurry mix tank vent operation
   - Installing a flexible chute material such as an absorbent fabric

5.3 Slurry Mix Tank

8. Ensure the slurry mix tank vent is functioning at all times during operation to mitigate dust issues and to control moisture upstream of the slurry mix tank.

9. The slurry mix tank vent scrubber must 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. A spare wet scrubber will reduce facility down time during maintenance.

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

11. 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 Transfer Lines

12. Do not allow the slurry to remain still in the pipelines.

See Design Guideline 41 regarding maintaining velocity in the transfer lines.

5.5 Feed Pump (s)

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

5.6 Dosing and Slurry Concentration Control

14. Sample slurry prior to the reactor at a minimum of once per shift to prevent system upsets and allow for immediate operator management and action should it be necessary. If the MgO dose is changed periodically more frequent sampling is recommended.