Magnesium Oxide (MgO) Dosing Systems for Thermal Enhanced Oil Recovery

Guideline Development Report

May 30th, 2014

ALBERTA waterSMART
Water Management Solutions

Submitted by:

Angela Alambets, P.Eng.
Project Lead
WaterSMART Solutions Ltd.
#200, 3512 - 33 Street NW
Calgary, Alberta T2L 2A6

Submitted to:

Mike Najewski
Project Engineer
HPD Evaporation and Crystallization
Veolia Water Solutions & Technologies
23563 W. Main St., Route 126
Plainfield, IL 60544

Acknowledgements

The following is a list of the companies that participated in the development of the guidelines outlined herein. Thank you to all individuals who contributed through workshop attendance, one-on-one interviews, or as advisors. We especially thank Baymag, as a MgO powder supplier, and STT Enviro Corp for sharing their expertise and advice.

Finally, greatest thanks to Veolia Water Solutions and Technologies, for providing the opportunity to bring the companies together, complete the analysis, and develop proposed guidelines for use by the industry.

- Baymag
- Canadian Natural Resources Limited
- ConocoPhillips Canada
- Devon Energy Corporation
- Husky Energy
- Imperial Oil
- Nexen/CNOOC Limited
- Shell Canada
- Southern Pacific Resources Corporation
- Suncor Energy
- STT Enviro Corp
- Statoil

Executive Summary

Magnesium oxide (MgO) is used for many applications in various industries, namely for neutralizing acidic solutions and reducing silica, hardness and alkalinity in aqueous solutions. This report focuses on the use of MgO for thermal enhanced oil recovery systems in Alberta.

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 these challenges on an individual basis with their equipment suppliers and engineering consultants. However, many of the 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 management in new systems.

This report provides the background, methodology and analysis undertaken to develop design and operation and maintenance guidelines for MgO dosing systems. It 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. A second report, “Magnesium Oxide (MgO) Dosing System Design, Operation and Maintenance and Supply Chain Guidelines for Thermal Enhanced Oil Recovery”, draws on information from this report and can be used as a quick reference for operators in developing specifications and standard operating procedures (SOPs).

This report was developed using a collaborative process whereby 10 owner companies, an MgO powder supplier, and an MgO equipment supplier shared challenges and lessons learned. All company representatives had the opportunity to attend two workshops and participate in one-on-one interviews as system owners and operators. Design information was collected for analysis to compare to information on challenges and successful operations at each facility.

The main observation from this work 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, it can also fall off the tank walls to collect in the bottom of the tank or transfer lines.

For the most efficient silica removal, the hydration of MgO (the slaking reaction) should not occur in the slurry tank and transfer lines but should occur after the slurry reaches the downstream reactor. The lime impurities in the MgO powder product are in very low concentration and are therefore not a major concern. However, the slurry mix tank must be treated as a reactor, where temperature and water quality can have a significant impact on downstream influence of scaling in slurry transfer lines.

There were mixed results in examining the relationship with temperature and solids buildup. Nine facilities with water temperatures of approximately 40°C expressed issues related to plugging in the slurry mix tank and transfer lines. One facility with a temperature of 15°C also experienced these issues, and two companies reported that at colder temperatures, the MgO tends to drop out of suspension. This is common in slurry mixtures and may be the case with MgO slurry.

In principle, poor water quality should have an impact on solids buildup in the system and scaling. However, no correlations were found between water challenges related to solids or scaling. It is believed that as long as the velocity is high enough, scaling will not create challenges. A velocity of 2.5 m/s is proposed as the ideal slurry flow velocity in the system.

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 true, 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.

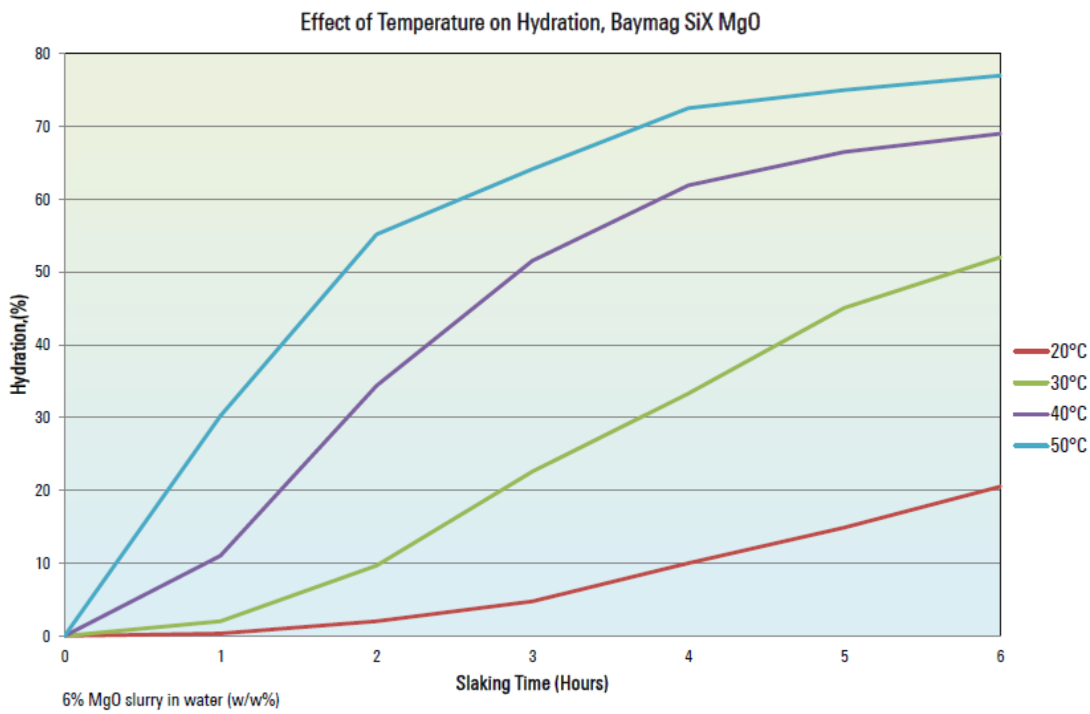
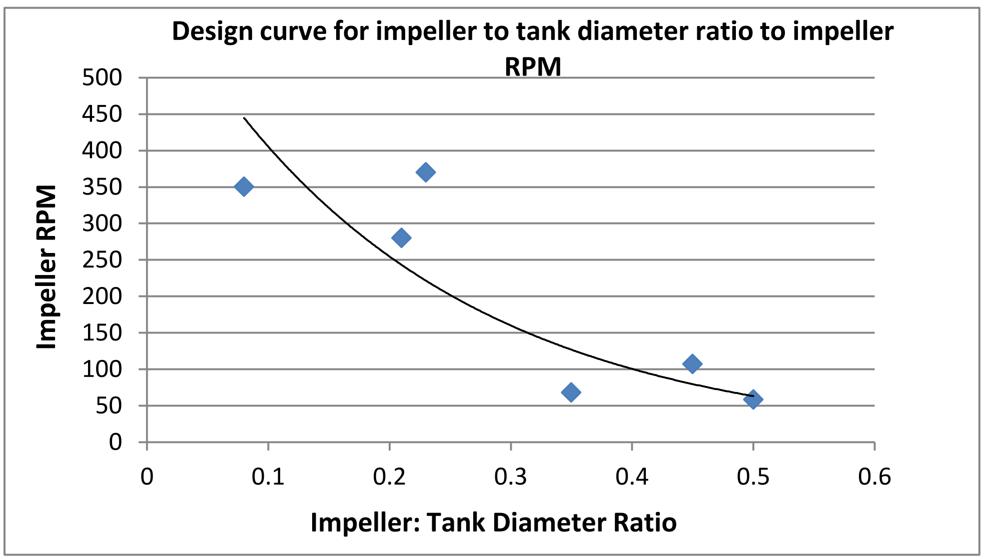
The design and operation and maintenance guidelines developed for each key area of interest in the MgO system are listed below according to the major process components, with the corresponding section of report where analysis and an explanation of development of the guideline are provided.

Summary of Proposed Design Guidelines

Guideline	**Report Section**
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	4.2.1

<table>
<tr><th>Guideline</th><th>Report Section</th></tr>
<tr><td>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.</td><td></td></tr>
<tr><td>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).</td><td>4.2.2</td></tr>
<tr><td>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.</td><td>4.2.3</td></tr>
<tr><td>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.</td><td>4.2.4</td></tr>
<tr><td colspan="2">MgO Transfer from the Storage Silo to the Tank</td></tr>
<tr><td>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.</td><td>5.2</td></tr>
<tr><td>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, and the advantages and disadvantages are outlined below. Do not use a rotary valve as the sole method of MgO powder volume control.
Advantages and disadvantages of loss-in-weight and volumetric hoppers
<table>
<tr><th colspan="2">Loss-in-weight</th><th colspan="2">Volumetric</th></tr>
<tr><th>Advantages</th><th>Disadvantages</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>More accurate MgO volume control</td><td>More expensive</td><td>Less expensive</td><td>Less accurate MgO volume control</td></tr>
<tr><td>Newer loss-in-weight hoppers have a user friendly interface</td><td>Area must remain dust free, and/or device cleaned regularly (more maintenance required than volumetric hopper)</td><td>Less maintenance required than with a loss-in-weight hopper</td><td>Plugging of level switched creates inconsistent process control</td></tr>
<tr><td></td><td>Older models are difficult to operate</td><td></td><td></td></tr>
</table>
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</td><td>5.2.2</td></tr>
</table>

Guideline	Report Section
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.	
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.	5.2.3
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.	5.2.4
Slurry Mix Tank	
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 the Effect of Temperature on Hydration curve, below. 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.	6.2.1

Guideline	Report Section
 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 the design curve for impeller to tank diameter ratio to impeller RPM, below, 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. 	

Guideline	Report Section
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.	
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 Design Guidelines 23 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.	6.2.3
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.	6.2.4
29. Size the agitator impeller diameter to be 1/3 to 1/2 of the tank diameter.	6.2.5
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 including the following: • Bubble tubes 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 caked 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 creates inaccurate readings.	6.2.6

Guideline	Report Section
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 23 regarding dust control.	
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.	6.2.8
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.	6.2.9
Slurry Transfer Lines and Feed Pump	
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.	7.2
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.	7.2.1
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.	7.2.2
45. Include permanent water flush lines upstream of the pump 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.	7.2.3

Guideline	Report Section
Water Quality and Temperature	
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.	8.0
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 8. 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.	9.2

Summary of Proposed Operational and Maintenance Guidelines

Guideline	Report Section
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.	4.2.1
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.	4.2.2
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).	4.2.3
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.	4.2.4

MgO Transfer from the Storage Silo to the Tank	
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	5.2.4
Slurry Mix Tank	
8. Ensure the slurry mix 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.	6.2.3
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.	6.2.4
Slurry Transfer Lines and Feed Pump	
12. Do not allow the slurry to remain still in the pipelines, as this will allow for MgO hydration and solids building causing plugging. 13. Backup pumps should be isolated and flushed before and after use.	7.2.1
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.	9.2

Table of Contents

List of Tables

List of Figures

1.0 Introduction

Magnesium oxide (MgO) is used for many applications in various industries, namely for neutralizing acidic solutions and reducing silica, hardness and alkalinity in aqueous solutions. This report focuses on the use of MgO for thermal enhanced oil recovery systems in Alberta.

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 currently operating in thermal enhanced oil recovery facilities in Alberta. These facilities were commissioned over several decades from the 1980s to present day and the operation and maintenance of the diverse MgO slurry systems pose numerous challenges to facility operators.

Although many of the 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 situation presented an opportunity to share knowledge within the industry on potential mitigation options to address challenges with current systems and develop guidelines for system design and operation that will improve the operation of existing and new systems.

In response, Veolia Water Solutions and Technologies retained Alberta WaterSMART to develop a set of design and operational and maintenance guidelines. A collaborative approach involving workshops and interviews with 10 owner companies, an MgO powder supplier, and an MgO equipment supplier was used to develop guidelines. This allowed for an 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 developed and implementation.

A **best practice** is a method or technique that has consistently shown results superior to those achieved with other means, and is used as a benchmark. 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 workshop, interviews, and information collected as part of this project indicate that the categories of design, operation and maintenance, and supply chain should be addressed. The results of the project are presented as guidelines for each category.

This report provides the information used and analysis undertaken to develop the guidelines. It 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. A second report, “Magnesium Oxide (MgO) Dosing System Design, Operation and Maintenance, and Supply Chain Guidelines for Thermal Enhanced Oil Recovery”, draws on information from this report and can be used as a quick reference for operators in developing specifications and standard operating procedures (SOPs).

2.0 Background

This section describes the major components in the MgO process and MgO slaking chemistry, summarizes some of the major challenges associated with the related systems, and describes the MgO system design process value chain.

2.1 MgO Process 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.

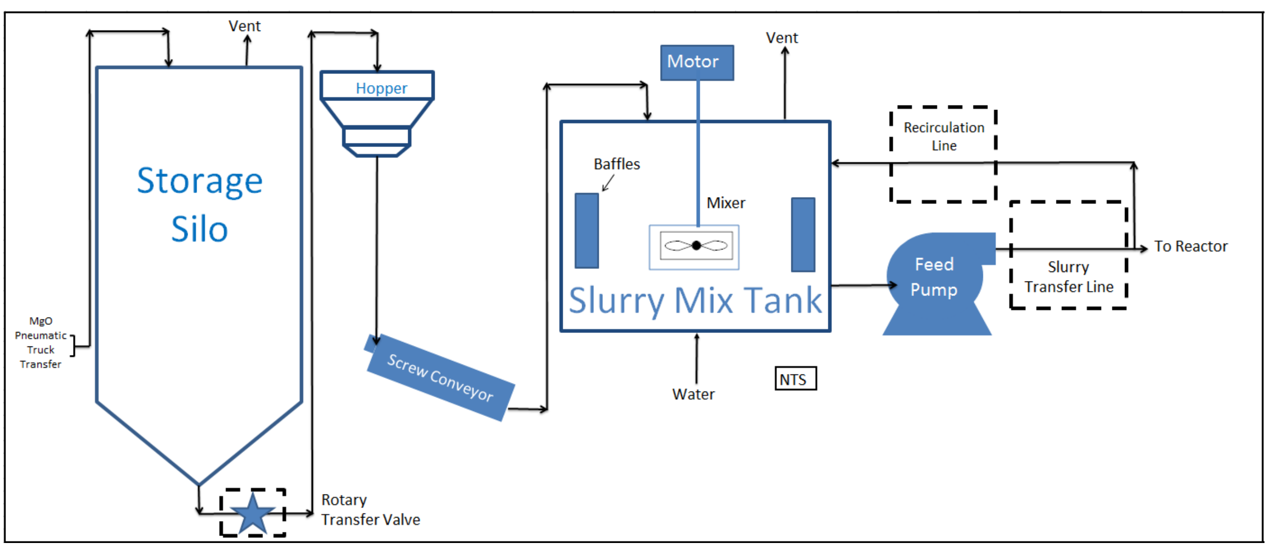


Figure 1. MgO Slurry System

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 may include a screw conveyor and a rotary transfer valve. These components are used as the MgO product slurry tank dosing control and measurement system. See Section 5.2 for a discussion of the components used to transfer the MgO product to the slurry tank and the associated proposed design guidelines.

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. See Section 6.0 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, 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 7.0 for a discussion on the slurry transfer lines and the feed pump and the associated proposed design guidelines.

2.2 MgO Design Process Value Chain and Stakeholder Roles

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 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 proposed guidelines in this report to develop their own requirements specific to MgO systems.

Table 1. MgO Design Process 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

2.3 MgO Slaking 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 makeup 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.

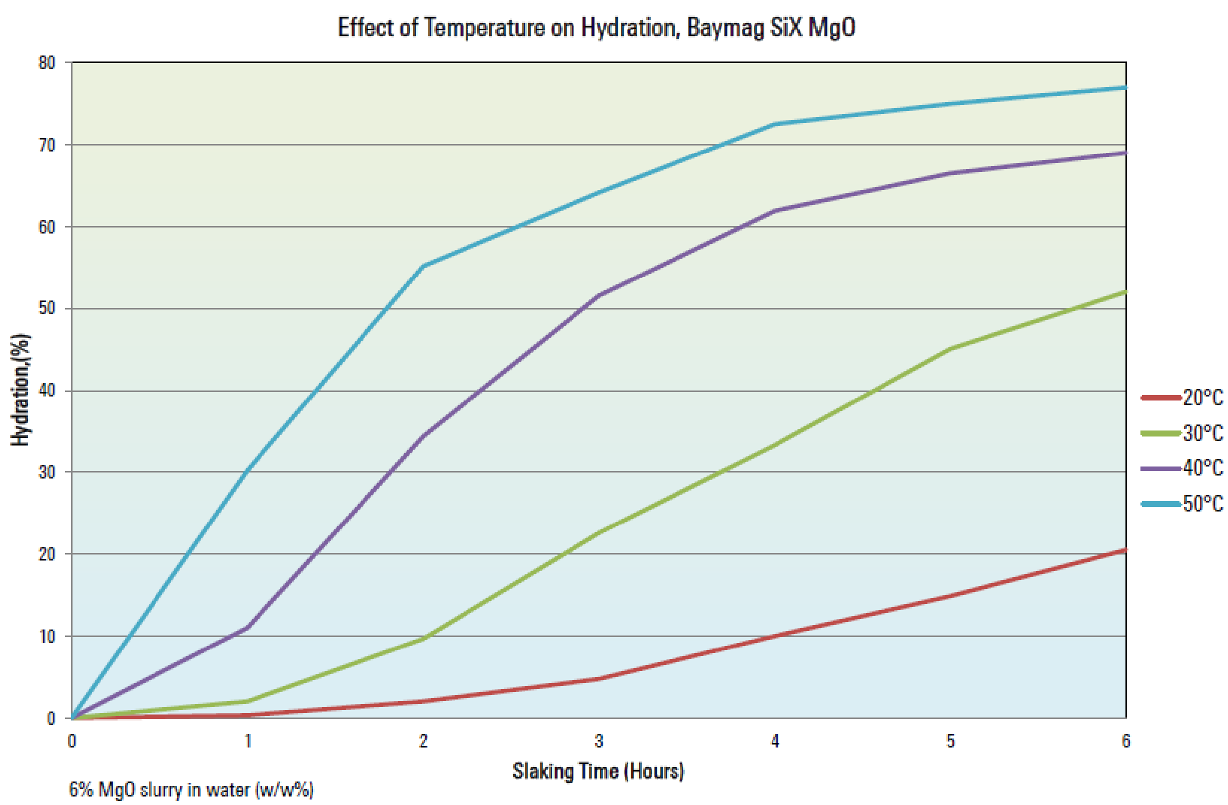


Figure 2. Baymag SiX MgO slaking curve

The silica removal efficiency 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 also 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.

2.4 MgO System Challenges

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

- An accumulation of MgO in the tank. Pieces of this accumulated material fall off and can block the tank outlet or interfere with the pump operation;
- Plugging of the piping upstream and downstream of the slurry pump. Scaling in elbows and uniform scaling around the inner surface of the piping have both been observed;
- The presence of moisture in the equipment can cause lumping of the MgO powder, which creates inconsistent delivery and clogs transfer systems and equipment. This creates problems in the hopper, rotary valve, and screw conveyor; 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
- Delivery location of MgO and raw water to slurry mix tank
- Slurry mix tank and baffle sizing and configuration
- Agitator impeller size, type and speed
- Slurry retention time
- Process piping
    - pipe type (hard pipe vs. hoses)
    - pipe size and configuration
    - slurry velocity
    - valve type
    - slurry feed location to the reactor (long vs. short slurry transfer distances)

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

3.0 Guideline Development Methodology

A collaborative approach involving 10 owner companies, an MgO powder supplier and an MgO equipment supplier was used to develop the guidelines in this report. This allowed for an 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 the development and implementation of their specifications.

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

The goal of the first workshop was to explain the project context to participants and to identify challenges experienced by operators of MgO systems that should be addressed by the development of system guidelines. The workshop had 37 participants, include participants from 10 owner companies, one product supplier (Baymag), one equipment supplier (STT Enviro Corp), and Veolia. During this workshop companies discussed challenges they had experienced with their MgO systems, likely causes of the challenges, and solutions they had tested or implemented in their design and operation. A summary of the findings from the first workshop can be found in Appendix 2 as part of the interview questionnaire.

Based on the findings from the first workshop, a one-on-one interview package was developed. This package was designed to discover what challenges each individual facility was experiencing, why they experienced the challenge and what they had done in to mitigate the challenge. Participants were also asked to provide design information in the hope that this information could be correlated to challenges or lack therefore (see Appendix 2).

Twelve facilities were analyzed. Three of the facilities with the same operator had the same components and issues up to the tank. After the tank, only two of these facilities had the same design and issues. Therefore, starting at the analysis of the tank, one additional was facility analyzed. 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 MgO system guidelines in this report.

At the second workshop, Alberta 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 “Magnesium Oxide (MgO) Dosing System Design, Operation and Maintenance, and Supply Chain Guidelines 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 SOPs.

The remaining sections of the report provide the results, analysis and proposed guidelines for each component, group of components, or key variables in the MgO system.

4.0 MgO Storage Silo

The MgO storage silo stores the MgO powder prior to the slurry mixing process. The product is transferred pneumatically into the silo by a third party truck hauling company, and is generally transferred out of the silo through a rotary valve or a screw conveyor.

The silo typically includes a level measurement system, mechanisms to promote MgO movement out of the silo including bin activators and/or an air injection system, a vent filter to remove dust from the silo, and a pressure relief valve.

Silos in the facilities analyzed ranged in capacity from 50 m^3 to 302 m^3, with most silos having a capacity between 150 m^3 and 250 m^3. The silo is typically a large vertical sealed tank with the top outside of the MgO process building. In general there is no specific temperature, pressure or humidity control on the silo, however there is always a pressure vacuum relief valve (PVRV) in place and a vent in place for dust control.

4.1 Results

Table 2 displays the data collected regarding MgO storage silos. The core equipment, equipment variations, and operational differences are shown, as well as the challenges experienced at each facility. The major challenges in relation to the storage silo were:

- Difficulty with dust control;
- Difficulty with product level measurement;
- Issues with moisture exposure leading to product sticking to the sides of the silo, plugging at the silo outlet or bridging over the outlet valve; and
- Inconsistent feed rate out of the silo.

Table 2. Equipment and challenge matrix – MgO storage silo

				Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11
Core equipment	Level measurement	Works well				X		X				Unknown		
		Works well enough for product inventory / shows trends					X		X	X	X	Unknown	X	X
		Works sometimes		X	X							Unknown		
		Does not work										Unknown		
		Guided Wave Radar	Centre	Unknown		X	X	X		X	X	Unknown		
			Off Centre	Unknown	X				X			Unknown		
		Ultrasonic										Unknown	X	
		Weight System										Unknown		X
		Air purge on measurement device		No	No	Yes	Yes	Unknown	No	Unknown	Unknown	Unknown	No	N/A
		PMs		Unknown	None	Unknown	Unknown	Monthly PMs	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown
	Silo outlet size			Unknown	Unknown	8"	Unknown	8"	Unknown	8"	2 x 6"	12"	Unknown	8"
	Downstream valve type	Rotary		X		X	X			X	X	X	X	X
		Knife		X	X	X	X	X	X			X	X	
		Screw Conveyor		X	X	x	X	X	X				X	
	Silo Vent	Bag House											X	
		Bin Filter						X	X			X		X
		"Vent Filter"		X	X	X	X			X	X			
	Silo Dimensions			6560mm ID x 19700mm	4267mm ID x 15446mm	3937mm ID x 21647mm	5580mm ID x 19650mm	4267mm ID x 21434mm	4240mm ID x 12420mm	4240mm ID x 18800m	4243mm ID x 18490mm	5629mm ID x 22100mm	3751mm ID x 73150mm	56300mm ID x 146300mm
	Silo Capacity			245 m^3	145 m^3	183 m^3	200 m^3	228 m^3	96.4 m^3	164 m^3	176 m^3	302 m^3	50 m^3	210 m^3
Process components and potential causes	Silo Vent PMs	Are there PMs?		Unknown	Unknown	Unknown	Yes	Vent has shaker	Unknown	Yes	Unknown	Unknown	Unknown	Unknown
		Frequency					3 months			Monthly				
	Vent on slurry tank	Is there a vent?		Yes	No	Yes	No[4]	Yes	Yes	Yes	No	No	No	Yes
		Vacuum on vent		Yes	N/A	Yes	N/A	No	Yes	Yes	N/A	N/A	N/A	Yes
		Wet scrubber on vet		Yes	N/A	Yes	N/A	No	Yes	Yes	N/A	N/A	N/A	Yes
		Vents outside		Yes	N/A	Yes	N/A	Yes	Yes	Yes	N/A	N/A	N/A	Yes
	Silo is located directly over the slurry Mix Tank			Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
	Opening in the top of the silo			Yes	No	No	No	No	No	No	No	No	No	No
	Aeration Pads			Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
	Silo / Bin Activator			No	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No
	Vibrator			Yes	No	No	No	No	No	Yes	No	Yes	No	No
	Impactors			No	No	No	Yes	No	No	No	No	No	Yes	Yes
	Aeration Cone			No	No	No	Yes	No	No	No	No	Yes	No	Yes
	Product transfer pressure (from truck into silo)			Unknown	Unknown	Unknown	12 PSI[3]	Unknown	5-15 PSI	6.5 PSI	6.5 PSI	101.5 PSI	30 PSI (max)	30 PSI (max)
Challenges	Product level measurement and control/management			X	X		X					Unknown	X	X
	Moisture exposure causes plugging / solids formation			X	X			X				Unknown	X	
	Inconsistent feed rate of product from the silo[1]									X	X	Unknown		
	Dust control Issues[2]			X	X		X	X				Unknown	X	X
	Bridging over valve				X							X		

Notes:

1. For most companies the feed rate from the silo is not a primary concern because it does not directly control the slurry control
2. Many companies noted that there was dust in the silo and it was hard to control, however it was not among the biggest issues in their MgO systems
3. Product was initially unloaded at 21 PSI, and a change to 12 PSI reduced problematic dust.
4. Historically there has been no vent system, but a vent system is being added now.

4.2 Analysis

4.2.1 Level Measurement

For five of the 11 facilities (45.5 %) analyzed, level measurement in the MgO storage silo was an issue. The causes varied and included false readings due to dust, failure due to lack of maintenance, and improper installation. Six out of 11 facilities (54.5%) indicated that while the level measurement on the silo was not exact it was sufficient for its purpose as product inventory control. One facility using silo level for control of MgO slurry tank dosing measurement was having significant challenges with proper dosing due to the inability of the device to continually operate properly. Only two out of 11 facilities (18.1%) indicated that the level measurement on their MgO system worked well.

Facilities that are having the most success with level measurement are using radar level measurement. 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 (refer to Ensuring Successful Use of Guided-Wave Radar Level Measurement Technology in Appendix 2). Another type of radar level measurement is also used, but a distinction by most companies between a cone type and a cable type were not made. Companies have had greater success when an air purge is present, but there was not enough information to support the use of this approach as a guideline. The air purge allows for the removal of dust from the instrument. One company noted that regular maintenance on the measurement device ensured that it continually functioned as necessary.

The weight scale level control approach creates challenges due to the inability to calibrate the system. Calibration requires a known weight of powder in the silo or ideally an empty silo. Due to continuous operation and low likelihood of redundancy for this large tank, continual operation limits the opportunity for proper calibration.

Dust buildup was reported to reduce the accuracy of ultrasonic level transmitters.

Proposed Design Guidelines

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.

Proposed Operational and Maintenance Guidelines

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.

4.2.2 Dust Control

Six out of 11 facility operators (54.5%) indicated that dust control in the silo was an issue, but none indicated it was a primary concern. The facility operators also indicated that dust control affected areas surrounding the silo such as the working area housed within the silo skirt.

All of the MgO storage silos have a vent; one facility operator was unsure if the vent was functional. No trends between dust control and vent type were identified.

One facility implemented preventative maintenance on its silo vent, which consisted of changing the silo filter once every three months. This resulted in a considerable improvement in dust control.

Proposed Design Guidelines

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).

Proposed Operational and Maintenance Guidelines

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

The pneumatic transfer of MgO product from the truck to the silo was consistently identified as a source of dust in the silo. The general range of product delivery is from five to 30 PSI with one facility transferring the product at 101.3 PSI. When one facility decreased the transfer pressure from 21 PSI to 12 PSI dust was reduced substantially. As long as pressure is sufficient to transfer the product from the truck to the tank, minimizing the transfer pressure appears to be an effective dust mitigation technique.

Discussions in workshop two indicated that the pneumatic feed line is typically rated for a pressure of 15 PSI. Based on the above information collected this has not limited the pneumatic delivery pressure for some facilities.

Proposed Operational and Maintenance Guidelines

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.

4.2.3 Moisture Control

Four out of 11 facilities (36.3%) experienced issues with moisture control in the silo causing plugging and solids buildup. Two of these facilities indicated that the moisture exposure was from the top of the silo through a broken thief hatch and an unfastened PVRV. 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 Guidelines

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).

The other two facilities identified that water vapour was entering the silo from the slurry mix tank. Neither facility had functioning vents on their slurry mix tanks. Without a functioning vent on the mix tank, the vapour 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 affect this moisture control challenge; it must be dealt with at the slurry mix tank. (See Section 6.0 – Slurry Tank.)

Ten out of 11 facilities (90.9%) had the MgO silo and all of the MgO powder transfer equipment directly above the slurry mix tank. If the slurry mix tank vent is not functioning properly, as the vapour rises it is more likely to become entrained in the silo and the MgO powder transfer equipment. The one facility that did not have the MgO storage silo located directly above the slurry mix tank did not have any issues with moisture control.

Proposed Design Guideline

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.

Two facilities reported bridging over their valve. One had a knife valve, and the other had a rotary valve. Both of these facilities batched MgO into the slurry mix tank, however, others without this issue are operating in the same way. Water temperatures were 55°C and 35-40°C, while most other operators used water with temperatures of 40°C. Therefore, no correlations can be made with valve bridging and system variables.

4.2.4 Inconsistent Feed Rate

Many participants indicated that an exact concentration of slurry is not necessary to operate the system efficiently, but ongoing inconsistency may cause challenges. An inconsistent feed rate from the silo was experienced at two facilities. These facilities did not indicate that plugging and solids formation or bridging over the valve was an issue. Table 3 shows the relevant system components at these facilities.

Table 3. System experiencing inconsistent feed rate out of the silo

	Outlet size	Valve type	Type of MgO flow system
Facility 7	8”	Rotary	Aeration pads, vibrator
Facility 8	Two parallel outlets – 6” each	Rotary	Aeration pads, bin activator

The MgO flow promotion systems used at the two facilities listed in Table 3 do not include aeration cones. The aeration pads are above the cone portion of the silo. None of the facilities with aeration cones had issues with inconsistent feed rate but it is unclear if the terminology for aeration cones is consistent between companies. This is not a strong enough trend to indicate that aeration cones improve consistent feed rates more than other aeration devices.

All of the facilities analyzed had some form of flow promoter, including impactors, bin activators or vibrators. In addition, nine out of 11 facilities (81.8%) had some form of air injection to facilitate discharge (aeration pads and/or aeration cones). A product supplier advised that impactors or similar mechanisms that physically shake the silo and product should not be used while the product is being loaded into the silo as they promote compaction of the product. Where shaking devices are used they should be used in conjunction with air; the air fluffs up the product causing the product to exhibit fluid-like flow, while the impactors shake the product down and out of the silo. A producer echoed this design criterion as a successful form of product movement out of the silo. Too much air can lead to over-fluidization causing product isolation challenges, and should therefore be avoided.

Proposed Design Guidelines

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.

Rotary valves are used in seven of the systems, which suggests they are not a mutually exclusive design feature causing inconsistent feed rates; however, Facilities 7 and 8 are the only ones that have a rotary valve downstream of the silo as the only method for MgO volume control. It is possible that using solely the rotary valve for MgO volume control either causes inconsistent feed rates or causes the inconsistent feed rates out of the silo to be more noticeable. (See Section 5.2.1.)

Proposed Operational and Maintenance Guideline

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.

5.0 MgO Transfer from the Storage Silo to the Tank

There are many different ways to transfer the MgO powder from the storage silo to the slurry tank. The main process components used are:

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

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 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. See the guidelines for the recommended use of rotary valves (Section 5.2.1).

The transfer device feeds the product to the slurry mix tank through a chute or an air gap. The chute is made of either hard pipe or fabric. Table 4 summarizes the components at each facility.

5.1 Results

Table 4 shows the information collected on the MgO powder transfer system. It shows the core equipment involved in the transfer, design components and the major process challenges associated with the transfer. The major challenges with MgO powder transfer were:

- Plugging of the transfer system components (mainly the screw conveyor and the chute); and
- Product volume or mass control.

Additional challenges included:

- Valve erosion issues
- Valve washout
- Solids buildup on level switches in hopper
- Plugging of screw conveyor
- Scaling in the screw conveyor
- Loss of product from screw conveyor
- Maintenance to clean out product buildup in screw conveyor
- Dust issues in the working area
- Difficulty in achieving low MgO feed rate
- Upsets caused by valve not addressed prior to upsets in downstream reactor.

Table 4. Equipment and challenge matrix – MgO transfer from silo to tank

			Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11
Core equipment	Rotary Valve, loss in weight hopper, screw conveyor, chute		X[8]								X		X
	Rotary Valve, hopper, screw conveyor, chute					X[8]						X[8]	
	Screw conveyor, chute			X[8]			X[8]	X[8]					
	Conveyor, hopper, conveyor, chute				X[8]								
	Rotary Valve, Chute								X[8]	X[8]			
Process components and potential causes	Chute Material		Hard Pipe & Rubber Boot	Unknown	Unknown	Canvas	8" Pipe	Absorbent Fabric	Flex Pipe	Hard Pipe	Hard Pipe	Open - Air Gap	Hose
	Air purge into hopper?		Yes	N/A[3]	No	No	N/A[3]	N/A[3]	N/A[3]	N/A[3]	Yes	No	Yes
	Air purge into screw conveyor?		No	No	No	No	No	No	N/A	N/A	Yes	No	No
	Air purge after screw conveyor?		Yes	Yes	No	No	No	No	N/A[6]	N/A[6]	No	No	Yes
	Water purge after screw conveyor?		No	No	No	No	Yes	No	N/A[6]	N/A[6]	No	No	No
	Lime and MgO slaked in the same tank?		No	No	No	No	No	No	No	No	No	No	Yes
	Vent on hopper	Is there a vent?	No	N/A	No	Yes	N/A	N/A	N/A	N/A	Yes	Yes	Yes
		Into Silo	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	No	Yes	No
		Outside	N/A	N/A	N/A	Unknown	N/A	N/A	N/A	N/A	Yes	No	Yes
		Vacuum on vent	N/A	N/A	N/A	No	N/A	N/A	N/A	N/A	Yes	No	Yes
	Bin Activator on Hopper		No	N/A[3]	No	No	N/A[3]	N/A[3]	N/A[3]	N/A[3]	No	Yes	No
	Hopper Type	Loss-in-weight	X	N/A[3]			N/A[3]	N/A[3]	N/A[3]	N/A[3]	X		X
		Volumetric		N/A[3]	X	X	N/A[3]	N/A[3]	N/A[3]	N/A[3]		X	
	Hopper Level Control	Loss-in-weight	X	N/A[3]			N/A[3]	N/A[3]	N/A[3]	N/A[3]	X		X
		Level switch		N/A[3]	X	X	N/A[3]	N/A[3]	N/A[3]	N/A[3]		X	
	Batching of MgO into tank		Yes[5]	Yes	Unknown	Yes	Yes	No	No	No	Yes	No	No
	Continuous MgO into tank		No	No	Unknown	No	No	Yes	Yes	Yes	No	Yes	Yes
	Screw Conveyor Length (mm)		Unknown	Unknown	7366	Unknown	812	203	N/A[6]	N/A[6]	Unknown	Unknown	Unknown
	Water Temperature		15 - 25°C	55°C	40°C	40°C	40°C	40°C	40°C	40°C	35-40°C	40 - 75°C	35°C
	Vent on slurry tank	Is there a vent?	Yes	No[2, 4]	Yes	No[9]	Yes	Yes	Yes	No[2]	No	No1	Yes
		Vacuum on vent	Yes	N/A	Yes	N/A	No	Yes	Yes	N/A	N/A	N/A	X
		Wet scrubber on vet	Yes	N/A	Yes	N/A	No	Yes	Yes	N/A	N/A	N/A	X
		Vents outside	Yes	N/A	Yes	N/A	Yes	Yes	Yes	N/A	N/A	N/A	X
		Vent PMs	None	N/A	Unknown	N/A	Unknown	None	Monthly	N/A	N/A	N/A	None
	Air purge into the slurry mix tank?7		No	No	No	No	No	No	No	No	No	No	No
	Twinned System		No	No	No	No	No	No	No	No	No	No	Yes
	System Directly over the Slurry Mix Tank		Yes	Slightly Offset	Unknown	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
challenges	Star valve plugging			N/A	N/A		N/A	N/A					
	Valve erosion issues			N/A	N/A	X	N/A	N/A	X	X			
	Valve Washout			N/A	N/A		N/A	N/A	X	X			
	Solids buildup on level switches in hopper			N/A			N/A	N/A	N/A	N/A		X	
	Plugging of screw conveyor		X	X			X	X	N/A	N/A	X	X	
	Scaling in the screw conveyor		X						N/A	N/A			
	Loss of product from screw conveyor		X				X		N/A	N/A		X	
	Maintenance to clean out product buildup in screw conveyor		X				X		N/A	N/A			
	Plugging of the chute		X	X		X			X	X	X	X	
	Dust issues in the working area		X	X		X	X		X	X	X	X	
	Slurry tank vent	Working	X		X	N/A	X	X	X		X		X
		Frequent plugging	X	X		N/A	X	X	X	X	X	X	
		Not working		X		N/A				X		X	
	Difficulty in achieving low MgO feed rate			X		N/A		X	X	X			
	Upsets caused by valve not addressed prior to upsets in downstream reactor					X			X	X			

Notes:

1. There is a vent, it does not work
2. Vent has been removed
3. No hopper
4. The vent returned to the tank causing plugging and failure
5. Screw Conveyor turns off while the rotary valve rotates to fill hopper
6. No Screw conveyor
7. An air purge after the screw conveyor (or the last element before the tank) could be considered an air purge into the tank, for this table it is not
8. There is an on/off valve upstream of these components, directly at the silo outlet
9. Vent is being added

5.2 Analysis

Of the 11 facilities assessed, all but one experienced challenges at some point in the MgO powder transfer system. The one system that did not experience challenges had a fully redundant system from the MgO powder silo onward. This allows for preventative maintenance to be performed on one half of the system while the other half of the system is operating. This redundancy avoids shutting down the system. Although it is costly to design and run the system this way, it is an effective way to prevent shutdown and manage the challenges associated with the entire system downstream of the silo.

Proposed Design Guideline

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.

Throughout the transfer system from the silo to the transfer mix tank, dust can create challenges with product buildup and poor air quality.

Proposed Design Guideline

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

5.2.1 Rotary Valve

Seven out of 11 facilities (64%) interviewed had a rotary valve in the MgO powder transfer system. Two of the 11 systems (18.1%) use the rotary valve as a volume control mechanism while the other systems only use it to fill a hopper. As Table 4 shows, the main challenges associated with the rotary valve are erosion, experienced by three out of the seven facilities (43%) and lack of detection of valve failure. In some cases, valve failure is not detected for up to six hours when the treated boiler feed water from the downstream reactor does not meet specifications.

Valve erosion was most prevalent in systems that used the rotary valve as the primary source of MgO powder volume control. Two of the three systems that experienced valve erosion used the rotary valve in this way. It is likely that erosion is not as noticeable or problematic in facilities that do not use the rotary valve as the primary method of MgO powder volume control because the valve does not control such a critical part of the process. 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 not be used. This is addressed in proposed Design Guidelines 8 and 9.

Some facilities have managed valve control and valve failure issues using alarm systems. Alarms can notify the operators every time the valve rotates or if the valve does not rotate. See Section 9.2.

5.2.2 Hopper

There are two types of hoppers in the MgO powder transfer process: the loss-in-weight hopper and the volumetric hopper. Six out of 11 facilities (54.5%) had a hopper. Three had loss-in-weight hoppers and three had volumetric hoppers. Volumetric hoppers use level measurement devices to fill, while loss-in-weight hoppers use a load cell to fill.

One of the reported challenges associated with the hopper was the ability to control the MgO flow into the hopper. Of the three facilities that use volumetric hoppers, one reported that the level switches become plugged if there is moisture in the system, creating challenges with MgO inflow operation and control.

The loss-in-weight hoppers are reported to have had many maintenance and operational issues. One facility reported having a loss-in-weight hopper in the past but removed it due to operational difficulties. Three facilities currently operating loss-in-weight hoppers had no challenges with operating them. The advantages and disadvantages of these two types of hoppers are noted in Table 5 as part of the proposed Design Guidelines.

Much of the moisture that causes plugging in the hopper originates from the warm water vapour in the slurry mix tank. To manage this issue, facilities should ensure that there is proper venting in the tank.

Four out of five facilities (80%) had a vent on their hopper. Three of these facilities had success with their hoppers. The facility without a vent did not report any challenges, while the facility that had the least success with its hopper vented from the hopper into the silo. It is not conclusive that the hopper must have a vent, but it may add to the operability and flexibility of the system. If there is a vent, it should vent outside and not into the silo.

Three out of the five facilities (60%) that had hoppers had an air purge into the hopper, and none of these facilities reported challenges with operating the hopper or with rotary valve plugging. Based on the process and instrument diagrams (P&IDs) the air purge is located on the side at the top of the hopper, which may help to prevent moisture in the equipment between the hopper and the silo. Of the two facilities that did not have an air purge, only one reported challenges operating the hopper.

Proposed Design Guidelines

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, and the advantages and disadvantages are outlined in Table 5. Do not use a rotary valve as the sole method of MgO powder volume control.

Table 5. 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.

5.2.3 Screw Conveyor

Nine out of 11 facilities (81.8%) have at least one screw conveyor. Of these facilities, seven use the screw conveyor as the volumetric control to regulate the MgO slurry concentration.

The main challenge associated with the screw conveyor is plugging. Six out of nine facilities (66.7%) reported this as an issue, and one facility noted that it was the biggest issue they had in the operation of their MgO system.

Plugging in the screw conveyor is mainly due to moisture. The presence of moisture must be managed by ensuring the slurry mix tank is properly vented. This is identified in proposed Design Guideline 23.

Results also showed that chute material may influence plugging. One company reported a considerable decrease in plugging in the screw conveyor after having changed material of the chute from hard pipe to absorbent material. This is further discussed in Section 5.2.4.

Other companies have added air or water purges after the screw conveyor to attempt to address the plugging, and have reported marginal success. Four out of nine facilities (44.4%) that have a screw conveyor have an air purge either into the end of the screw conveyor or directly after the screw conveyor. One out of nine facilities (11.1%) has a water purge after the screw conveyor.

An air purge after the conveyor acts as a source of clean air into the slurry mix tank. This should be the only source of air into the slurry tank. This single source of air inflow promotes flow through the tank away from the MgO powder inlet, conveying water vapour away from the inlet and preventing product buildup. It is therefore recommended that an air purge into the screw conveyor or directly after the screw conveyor be used. An air purge is recommended after the screw conveyor both to avoid moisture issues in the MgO powder transfer system and to facilitate tank venting.

Where an MgO supply batch mode is used, a water purge after the screw conveyor is meant to flush the chute while the screw conveyor is not operating. If a water purge is used there must be an automatic isolation valve between the screw conveyor and the purge that is closed while the water is flushing the area. There is no conclusive evidence that a water flush after the screw conveyor is effective at increasing operability. The only facility that had implemented a water flush identified plugging in the screw conveyor as its greatest operational challenge.

Proposed Design Guideline

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.

One facility originally installed a ribbon screw conveyor and recently changed to a conventional closed flight conveyor. While using the ribbon screw conveyor the facility had challenges associated with open flow of MgO powder through the conveyor, but this is no longer an issue with the conventional closed flight conveyor. The use of a ribbon screw conveyor could also lead to moisture control issues, as there would be a more open trajectory for water vapour to move through the screw conveyor. As such, the use of ribbon screw conveyors is not recommended.

Proposed Design Guideline

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.

There was no definite trend correlating the continuous or batch operation of a screw conveyor to plugging. Three of the four systems (75%) that batched the MgO into the tank reported plugging in the screw conveyor while two of the three systems (67%) that ran the conveyor continually reported plugging in the screw conveyor.

Batching the MgO powder from the silo to the slurry mix tank may slightly increase plugging challenges in the screw conveyor. When the conveyor is operating, continuous movement of the conveyor prevents MgO powder from sitting in the conveyor where it may be exposed to vapour and form solids. In addition, the continual forward movement of the product does not allow water vapour to move into the conveyor.

If the 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.

Proposed Design Guideline

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.

5.2.4 Chute

Seven out of eleven facilities (63.6%) had plugging issues in the chute from the screw conveyor or rotary valve to the slurry mix tank.

One of the eleven facilities had an air gap instead of a chute between the conveyor and the mix tank. This facility operator reported severe dust issues surrounding the mix tank as well as loss of product between the conveyor and the tank. It is recommended that the end of the conveyor or the rotary valve have a secured chute to the slurry mix tank to avoid these issues.

Table 6 shows the materials used to construct the chute at the 10 facilities with chutes.

Table 6. Summary of chute material and plugging issues

Chute material	Facilities using this material	Facilities reporting plugging	Percentage reporting plugging
Unknown	2		
Hard pipe	4	3	75%
Flex Pipe	1	1	100%
Hose	1	0	0%
Canvas / Absorbent Material	2	1	50%

Two facilities have changed their chute material from hard pipe to either canvas or an absorbent fabric. Although one facility still reported plugging, the other facility reported that the absorbent fabric had decreased plugging in both the chute and the screw conveyor. The absorbent fabric allows clean dry air flow into the chute. This, combined with a properly functioning vent on the slurry mix tank creates a steady flow of clean dry air through the chute and into the slurry mix tank. This helps to convey water vapour away from the chute, thereby preventing plugging. Another method of introducing air is an air purge near the end of the screw conveyor, as identified in proposed Design Guideline 12.

Facility operators with flexible chute material, including flex pipe or hose chutes, found the major advantage was the ability to remove plugging by manual kneading, providing for simpler maintenance. Companies that had hard pipe chutes noted that when the chute became plugged it was very difficult to maintain the chute. Therefore, if the chute material is hard pipe, a cleanout port should be installed to allow for easy maintenance.

Proposed Design Guidelines

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.

Proposed Operational and Maintenance Guideline

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

6.0 Slurry Mix Tank

The MgO powder and water are added to the slurry mix tank where they are mixed with an electric power agitator to produce MgO slurry. The main components of the tank are the baffles, the agitator and the venting system. To ensure proper mixing of the slurry, the baffles, agitator and tank must be properly designed and sized. The venting system is crucial to prevent formation of solids above the liquid level in the tank and to prevent plugging in other upstream process components.

6.1 Results

The MgO slurry mix tank created significant challenges in at least nine out of 11 facilities. Table 7 summarizes the data collected on the slurry mix tanks. The table shows the main equipment components in the slurry mix tank, the different process components that may lead to challenges in the tank, and the main challenges reported in the slurry mix tank. The main challenges regarding the slurry mix tank were:

- Solids buildup on the sides of the tank above and below liquid level,
- Dust control,
- Vent plugging,
- Plugging of the suction nozzles out of the tank,
- Challenges with slurry tank level measurement, and
- Foaming.

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
Core equipment	Agitator	Speed	1750 RPM	280 RPM	107 RPM	Unknown	2200 rpm	1200 - 1300 RPM	Unknown	350 PRM	68 RPM	370 RPM	58 RPM	Unknown
		Diameter	1016 mm	348 mm	top: 660 mm bottom: 605 mm	Unknown	305 mm	356 mm	Unknown	151 mm	1270 mm	419 mm D, 1321mm DBP, 305mm OBD	1220 mm	Unknown
		Agitator to Tank Diameter Ratio	0.47	0.21	top: 0.45, bottom: 0.21	Unknown	0.17	0.25	Unknown	0.08	0.35	0.23	0.50	Unknown
		Type	2 Impellers	1 impeller, 3 blades	2 impellers	2 Impellers	1 impeller, 3 blades	Blade	Unknown	1 impeller	1 Impeller, 3 blades	3 blades, Unknown # of Impellers	1 impeller	2 Impellers
		Centred	X	X	Unknown	Unknown		X	X		X		X	Unknown
		At an angle			Unknown	Unknown	X			X		X		Unknown
	Baffles	Are there baffles?	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	No
		Number of baffles?	4	N/A	4	Unknown	N/A	4	4	N/A	4	N/A	4	N/A
		Below NLL?	Unknown	N/A	Unknown	Unknown	N/A	Unknown	Unknown	N/A	Yes	N/A	Unknown	N/A
		Size (ratio to tank size)	0.058	N/A	0.087	Unknown	N/A	0.091	Unknown	N/A	0.111	N/A	0.083	N/A
		Is there wall clearance	Unknown	N/A	Yes	Unknown	N/A	Unknown	Unknown	N/A	Unknown	N/A	Unknown	N/A
		Wall clearance to tank ratio	Unknown	N/A	0.0157	Unknown	N/A	N/A	Unknown	N/A	Unknown	N/A	Unknown	N/A
	Vent on slurry tank	Is there a vent?	Yes	No2	Yes	No1	Yes	Yes	Yes	No2	No	No2	Yes	No1
		Vacuum on vent	Yes	N/A	Yes	N/A	No	Yes	Yes	N/A	N/A	N/A	Yes	N/A
		Wet scrubber on vent	Yes	N/A	Yes	N/A	No	Yes	Yes	N/A	N/A	N/A	Yes	N/A
		Vents outside	Yes	N/A	Yes	N/A	Yes	Yes	Yes	N/A	N/A	N/A	Yes	N/A
		PMs	None	N/A	Unknown	N/A	Unknown	None	Monthly	N/A	N/A	N/A	None	N/A
	Distance from MgO powder inlet to tank vent		610 - 915 mm	N/A	Unknown	Unknown	Unknown	610 - 915 mm	Unknown	N/A	2025 mm	N/A	1000 mm	Unknown
	Level Measurement	Is the device accurate?	Unknown	Unknown	X		Unknown	Yes	Unknown	Unknown	X	X	X	
		Plugging Issues / Buildup of solids	X	Unknown		Unknown	X		X	X		X		Unknown
		PMs	Unknown	Unknown	Unknown	Unknown	X	Unknown	Unknown	Unknown	Unknown	Water flush daily	Water flush daily	Unknown
		Unknown Level Measur. Device		X		X								X
		Radar	X					X4			X			
		Float Switch					X							
		Differential Pressure								X				
		Ultrasonic			X									
		Bubble Tube							X			X	X	
Process components and potential causes	Water Quality	Temperature	15-25°C	55°C	40°C	40°C	40°C	40°C	40°C	40°C	35-40°C	40 - 75°C	35°C	40°C
		TOC	280 ppm	Low	Unknown	155 ppm	372 ppm	<5 ppm	550 ppm	560 ppm	165 ppm	260 ppm	150 ppm	162 ppm
		Conductivity	3600 uS/cm	Low	40 uS/cm	12,000 uS/cm	4275 uS/cm	150	10,500 uS/cm	9,500 uS/cm	12,600 us/cm	19,000 uS/cm	19,000 uS/cm	11,100 uS/cm
		Hardness	Unknown	Zero	0.3 ppm	0 ppm	<0.5 ppm	Unknown	<0.5 ppm as CaCO3	<0.5 ppm as CaCO3	<1 ppm	560	0.4-400 ppm	0 ppm
		Carbonates	270 ppm	Zero	Unknown	Unknown	160 ppm	100 ppm	Unknown	Unknown	216 ppm	Unknown	Unknown	Unknown
		Alkalinity	250 ppm	Low	Unknown	713 ppm	364 ppm	<10 ppm	462 ppm as CaCO3	750 ppm as CaCO3	361 ppm	166	82	681 ppm
		Oil & Grease	29 ppm	Low	0.5 ppm	12 ppm	15 ppm	Unknown	0.3 ppm	0.2 ppm	0 ppm	Nil	Nil	4.5 ppm
	PMs	Water Flush	None		Unknown	No		Yes	Yes		Yes	Unknown	Unknown	No
		Acid Flush	None	Yes	Unknown	Yes	Yes		Yes	Yes		Unknown	Unknown	Yes
		Frequency		5-6 months	Unknown	6 months	3-4 months	Weekly	2-3 months	Monthly	Daily	Monthly	Monthly	6 months
	Are recirculation lines used?		None	Yes	Yes	Yes	Yes	No	No	No	No	No	No	Yes
	MgO is batched into tank		Yes	Yes	Unknown	Yes	Yes	No	No	No	Yes	No	No	Yes
	Batch[5]										X			
	Continuous with recycle[7]			X7	X	X	X5							X
	Continuous with VFD[9]		X						X	X		X	X	
	Once through system[8]							X						

			Facility 1	Facility 2	Facility 3	Facility 4	Facility 5	Facility 6	Facility 7	Facility 8	Facility 9	Facility 10	Facility 11	Facility 12
	Location of water inlet to tank	Top			X	X		X	X	X				X
		Side above NLL	X									X		
		Side below NLL		X			X	X					X	
		Bottom									X			
	Location of MgO inlet to tank	Top centre		X	X	X		X	X	X				X
		Top to the side	X				X				X	X	X	
	Slurry concentration		0.05	2-5%	2-5%	2-5%	5-10% (8%)	0.005	Unknown	Unknown	0.03	10% max.	0.06	2-5%
	Retention Time	Designed Retention Time	Unknown	Unknown	42 mins	Unknown	None	Unknown	20 min	20 min	Unknown	10 min	10 min	Unknown
		Operating Retention Time	30-40 min	Unknown	Unknown	Unknown	Unknown	Unknown	14 min	16 min	2 - 6 hrs	10 - 30 min	10 - 30 min	Unknown
	Estimated Percent Hydration (%)		1%	Unknown	Unknown	Unknown	Unknown	Unknown	4%	6%	35 - 70%	~7 - 20%	4%	Unknown
Challenges	Solids Buildup Above Liquid Level	Unknown cause		X							X			
		Due to splashing	X				X	X	X	X		X		
		Due to dust & moisture	X					X	X	x		X		
	Dust control		X	X			X	X	X	X	X	X		
	Vent plugging		X	X		N/A	X	X	X	X2	X	X2		N/A
	Achieving desired slurry concentration						X	X	X	X				
	Buildup of product	on sides		Unknown	Unknown	X	X	X	X	X	X			X
		on bottom		Unknown	Unknown	X	X	X	X	X	X			X
	Plugging of suction nozzles					X	X	X	X	X		X		X
	Slurry tank level measurement			X		X	X		X	X				X
	Foam					X								X

Notes:

1. Vent to be added.
2. Vent plugged and now is off.
4. Two devices - ultrasonic and free space, both work.
5. Batch - Full batch system both into slurry mix tank and out of slurry mix tank
6. There is a recycle line on this system, it is rarely used except for acid washes.
7. Continuous with recycle - Continuous varying MgO flow into slurry mix tank, continuous varying water flowrate into slurry mixtank and continuous constant slurry flow out of tank (with recirc)
8. Once through system - Continuous varying MgO flow into slurry mix tank, continuous constant water flowrate into slurry mixtank and continuous constant slurry flowrate out of tank
9. Continuous with VFD - Continuous varying MgO flow into slurry tank, constant water flowrate into slurry mixtank, varies flow out of mix tank (pump on VFD)

6.2 Analysis

Most of the challenges related to the slurry mix tank were caused by improper mixing and tank design. Improper mixing can be caused by inefficient tank design parameters such as tank sizing, baffle design, and agitator type and size. Additionally, challenges associated with the tank are exacerbated by poor venting in the tank.

While various design components are discussed herein, and correlations made between these components and various challenges, it is likely that no single design component or operational difference is responsible for any given challenge. For example, at a facility that is missing both tank baffles and venting it is likely that 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, operate, and maintain the slurry mix tank based on data analysis in addition to anecdotal experience and technical knowledge.

6.2.1 Solids Buildup

A number of variables contribute to solids buildup, including temperature, slurry residence time, agitator design, and location of inputs to the tank. Designing for only one of these variables will not ensure solids buildup is prevented.

All of the companies that attended the first workshop indicated that they were not aware of any modelling that had been undertaken for their systems to ensure proper mixing. In addition, a package supplier indicated that slurry mix tanks and their components had typically not been designed using mixing models.

Proposed Design Guideline

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.

Ten out of 12 facilities (83%) experienced solids buildup either above the normal slurry liquid level or on the sides and bottom of the slurry mix tank. Eight facilities had solids buildup above the liquid line and eight facilities had solids buildup on the sides and bottom of the tank.

Table 8 summarizes information for the only facilities without solids buildup below normal liquid level in the tank. These facilities are referred to throughout the analysis.

Table 8. Summary of facility data with no solids buildup in tank

Parameter	Facility 1	Facility 10	Facility 11
Slurry Concentration	5%	10% max.	6%
Slaking Parameters			
Retention time (Design)	Unknown	10 min	10 min
Retention time (Actual)	30 – 40 min	10 – 30 min	10 – 30 min
Water Temperature	15 – 25°C	40 – 75°C	35°C
Slaking efficiency (from Figure 2)	0%	8% – 13 %	0– 2%
Water Quality			
TOC	280 mg/L	260 mg/L	150 mg/L
Conductivity	3,600 uS/cm	19,000 uS/cm	19,000 uS/cm
Hardness	Unknown	560	0.4-400 ppm
Carbonates	270 mg/L	Unknown	Unknown
Alkalinity	250 mg/L	166 mg/L	82 mg/L
Oil & Grease	29 mg/L	Nil	Nil
Design Components			
Agitator Impeller Diameter	40"	16.5" D, 3 blades, 52" DBP, 12" OBD	48" D
Agitator to Tank Diameter Ratio	0.47	0.23	0.50
Agitator Type	2 Impellers	3 blades, Unknown # of Impellers	1 impeller
Agitator Speed	1750 RPM	370 RPM	58 RPM
Agitator Centred	X		X
Agitator At an angle		X	
Baffles	Yes	No	Yes
Baffle: Tank Ratio	0.06	N/A	0.08
PM Water flush	None	Unknown	Unknown
PM Acid flush	None	Unknown	Unknown
PM frequency	N/A	Monthly	Monthly

Retention Time, Temperature, and Slaking Efficiency

It is desirable to have MgO slaking (hydration) occur only in the downstream reactor, as discussed in Section 2.3. A long retention time and higher temperature will increase the chance of slaking before the reactor.

Lime impurities in the tank are limited to approximately 1.7% concentration and are also typically only approximately 50% reactive. Depending on reactivity, lime will hydrate completely in 10 to 30 minutes. Although the slaking of lime is an exothermic reaction, the limited concentration will have a minimal impact on the MgO hydration reaction. However, alkalinity in the water source has the potential to react with the lime to cause scaling in the pipelines, and should be managed accordingly.

There does not appear to be any correlation between water temperature and solids buildup in the tank. Facility 1 has the lowest water temperature and reports buildup above normal liquid level due to splashing as well as dust and moisture, but does not report buildup below normal liquid level. Facilities 2 and 11 have the highest water temperature and both have buildup above normal liquid level but not below.

Retention times ranged from 10 minutes to six hours. One facility operator indicated that residence time was not considered as a key design parameter and there was no residence time design objective.

The facility with the two to six hour actual residence time range has makeup water temperatures between 35 and 40°C. This facility had issues with solids buildup on the sides and on the bottom of the tank, including above the liquid level. This was a common challenge for many facilities; however, if this retention time is compared to the slaking curve, at a water temperature of 35-40°C the MgO is likely already past 25% hydration in the tank, and could reach up to 70% hydration in the tank.

Many parts of the system must be considered to achieve an optimal retention time including tank size, dosing approach, and recirculation. Table 8 summarizes information for three facilities with retention times of 10 to 40 minutes, which were the only facilities with no issues with solids buildup below normal liquid level on the sides or bottom of the tank. One other facility did not know if they had this issue. The three facilities had slurry concentrations similar to or higher than many others with slurry concentrations of 2-5 %. Their slaking efficiencies, identified based on Figure 2, range from 0% to 13%. The other facilities that had solids buildup issues and known retention times had slaking efficiencies above 13%. Therefore, it appears that a slaking efficiency threshold of 13% is a practical design objective to reduce the amount of solids buildup in the slurry tank.

To prevent MgO hydration, lower temperatures should be used.

In addition, other factors are likely contributing to the successful mixing at these facilities. For example, the large size of agitator impeller diameter likely contributes to improved mixing. Other parameters outlined in Table 8 will be discussed later in the report.

Proposed Design Guideline

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.

Solids Buildup Above the Normal Liquid Level

Of the eight facilities that had solids buildup above the normal liquid level, five noted that the buildup was from slurry splashing as well as dust and moisture, while one facility noted that the buildup was just from slurry splashing. The remaining two facilities were unsure of the cause of buildup.

There is no conclusive correlation between solids buildup above the normal liquid level and with operating a vent, the presence of baffles, or the use of recirculation lines:

- Half of the facilities with solids buildup above the normal liquid level did not have a vent, while half of the facilities without buildup also did not have a vent.
- Half of the facilities that experienced solids buildup above the normal liquid level had baffles, and 75% of facilities without this buildup had baffles.
- Two out of five facilities that are using recirculation lines have buildup above normal liquid level. Six out of seven facilities that are not using recirculation lines have buildup above normal liquid level.

All of the facilities with the agitator at an angle experience buildup above normal liquid level due to splashing. Only three out of six of the facilities that have the agitator in the centre experience solids buildup due to splashing, while two of these facilities have buildup above liquid level due to unknown causes. This suggests that agitators at an angle may increase the potential for splashing, causing solids buildup. Additional impacts of agitators on mixing are discussed in Section 6.2.5.

As further discussed in Section 6.2.5, if the ratio of the impeller to tank diameter is 1/3 to 1/2, information assessed suggests that an impeller speed as low as 60 RPM is sufficient for mixing. All facilities with mixing speeds over 350 RPM have solids buildup due to splashing. Ideal impeller speeds are therefore between the 60 and 350 RPM range. However, all mixing variables must be considered together to ensure adequate mixing.

Figure 3 shows the correlation of impeller to tank diameter versus the speed of the mixer for all facilities that did not have splashing. Based on the impeller to tank diameter of a system, this graph can be used to identify the maximum practical impeller speed to prevent splashing. The only part of the curve that should be used is for ratios between 1/3 and 1/2.

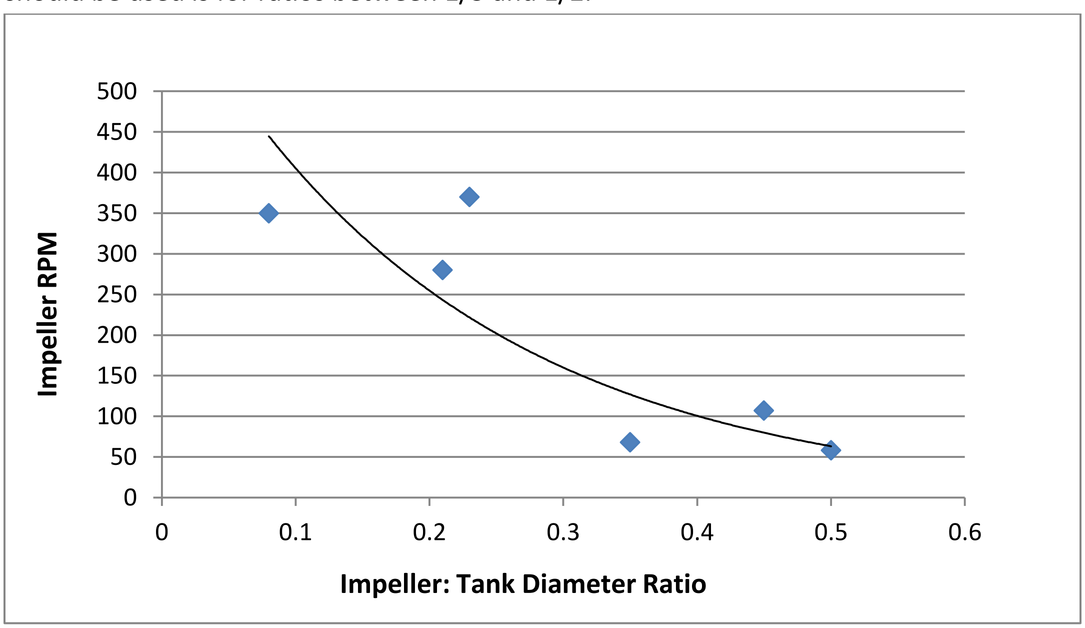


Figure 3. Design curve for impeller to tank diameter ratio to impeller RPM

All of the facilities with solids buildup due to dust and moisture had the MgO product inlet and water inlet entering very close to each other (Facilities 1, 7, 8, and 9). Three of those facilities had continuous product dosing systems, while the other two had dosing systems with a VFD on the feed pump. See Section 9.0 for a description of the dosing systems.

This suggests that the MgO product inlet and water inlet should, at a minimum, have some separation to prevent solids buildup due to dust and moisture. However, locating the water inlet in the bottom of the tank is the ideal design to prevent solids buildup in the tank.

Proposed Design Guideline

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.

Solids Buildup below the Normal Liquid Level

All five facilities with recirculation lines had solids buildup below the normal liquid level. Four out of seven facilities without recirculation lines had buildup below the normal liquid level. However, these facilities had very high mixing speeds, no baffles, or very long retention times, and up to a 50% slaking efficiency. In addition, all of the facilities without solids buildup did not have recirculation lines. This indicates that there is likely a relationship between recirculation lines and solids buildup below the liquid level, which is likely caused by a higher residence time created by the recirculation of slurry.

The impact of agitator impeller diameter is discussed in section 6.2.5.Three of the four facilities with solids buildup due to dust and moisture performed maintenance as follows:

- One performed a weekly water flush,
- One performed a water and acid flush every two to three months, and
- One undertook a monthly acid wash flush.

In addition, the three facilities without solids buildup below the tank had either none, or monthly PMs. This shows that performance maintenance will not necessarily have an impact on solids buildup in the tank.

Proposed Design Guidelines

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.

6.2.2 Tank Sizing

The capacity of slurry mix tanks at the facilities assessed varies from 2.5 m^3 to 49 m^3. It was not possible to draw conclusions for ideal tank sizing from the information available. Discussion of tank sizing is most applicable for other design parameters such as baffle size and agitator diameter, which are discussed in Sections 6.2.4 and 6.2.5.

Nonetheless, tank size will have an impact on the residence time of the MgO slurry from initial mixing until it reaches the downstream reactor. Thus, an appropriate guideline is to size the tank to obtain an optimal residence time that will prevent MgO slaking before the downstream reactor, while allowing enough time for slaking of lime impurities, as noted in proposed Design Guideline 17.

6.2.3 Dust Control and Tank Venting

An ideal design for a vent system on the slurry mix tank includes a vacuum on the vent. The venting system on the tank should be sized to mitigate dust issues, and it should remove moisture from the tank to prevent its ingress into the upstream components.

Five out of 12 facilities (41.7%) reported that they did not have a vent on the slurry mix tank. Two were in the process of adding venting and three reported vent plugging or failure that led to decommissioning of the vent.

Dust is created when the MgO powder is dropped through the chute into the tank. Dust issues in the slurry mix tank were reported by eight out of 12 facilities (67%). Dust is created when the MgO powder is dropped through the chute into the tank. Two facilities that did not have any issues with dust control had functional vents on their slurry mix tanks.

Two companies indicated that the vents operated well, and both operated with a vacuum. In addition, a supplier indicated this is an ideal design parameter. These were the only two facilities that did not report any plugging in the components upstream of the slurry mix tank, mainly the screw conveyor and the chute.

In addition, the use of a wet scrubber performed well for many companies. Although these may beneficially affect operations, the information collected shows no correlation between the use of a wet scrubber and reduced moisture in the slurry tank dosing system.

The slurry mix tank should have a functioning vent at all times during operation to mitigate dust issues and help prevent plugging upstream of the tank.

Proposed Design Guideline

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 Design Guidelines 23 to 26 for tank vent system design.

Proposed Operational and Maintenance Guidelines

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.

Eight out of 10 facilities (80%) that have vents reported vent plugging issues. One facility had removed the vent completely as a result of plugging issues, and one reported having a vent that did not work due to vent plugging.

The temperature of the makeup water at the facilities that have vent plugging varies from as low as 15°C to as high as 55°C, with six out of eight facilities (75%) having a makeup water temperature of around 40°C. Both of the facilities that did not report vent plugging were using makeup water with a temperature around 40°C. Because the temperature of the makeup water varies so widely and there was no discrepancy in makeup water temperature between facilities with and without vent plugging, no correlation can be made between vent plugging and makeup water temperature.

The distance between the MgO powder inlet to the tank and the tank vent is known for four facilities, and varies from 610mm to 2025mm (24 to 80 inches). Three of these facilities had vent plugging and distances varied from 610 to 2025mm (24 to 80 inches), whereas the one facility that did not report vent plugging had a distance of 1000mm (39.4 inches). There is not enough data to develop a correlation between vent plugging and distance between the MgO powder inlet and the tank vent. However, the vent should not be placed directly beside the MgO powder inlet as the vent will suck up the powder and plugging will occur more quickly.

Only one facility reported performing regular PMs on their slurry tank vent. At Facility 8, PMs are performed on the slurry tank vent monthly and the facility still experiences vent plugging. Therefore, no conclusions can be drawn regarding vent PMs and plugging but it is likely that PMs decrease the chances that the vent will 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 to monitor the need for maintenance; an increase in differential pressure will indicate that vent cleaning is necessary.

Information regarding vent sizing was not collected. However, 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

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.

Of the seven facilities that have vents on their slurry mix tanks, only two facilities did not report having vent plugging issues. Another facility operator reported that they had replaced a vent and the new vent has no problems. Five facilities have a slight vacuum on the vent, five have wet scrubbers on their vents and six vent outside.

One facility does not have a vacuum or a wet scrubber and vents inside. Although this facility did not report vent plugging issues, it was the facility that reported the most issues with moisture upstream of the tank, indicating that this vent is not operating properly.

One facility did not have a wet scrubber, but it did have a water purge entering the tank through the chute. This water purge may act similarly to a wet scrubber as the water droplets would drop down into the tank and attract the dust particulate. This facility did vent outside and has very few issues with its venting system.

Proposed Design Guideline

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

One inlet of dry fresh air into the system with a negative pressure on the vent will convey air and water vapour out of the vent. Having only one air inlet into the tank avoids short circuiting of damp air. Many companies discussed that an air purge into the vent may be useful; however, air from the surrounding facility should be adequate if the facility is dry. Two facilities have had success replacing the hard chute into the slurry mix tank with a canvas chute, therefore allowing air flow into the tank through the chute. See proposed Design Guideline 15.

Proposed Operational and Maintenance Guidelines

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.

6.2.4 Baffles

Five out of 11 facilities (45.5%) have removed the baffles from their slurry mix tank. All these facilities reported plugging issues in the slurry mix tank. One facility mentioned that removing the baffles had significantly decreased mixing efficiency leading to increased buildup and plugging. None of these facilities reported that the removal of their baffles had improved the operation of their system and only one reported that the slurry mix tank operated to a satisfactory level.

At least some of these facilities removed their baffles without consulting an equipment supplier. This is just one example of how operators have modified the system without supplier consultation resulting in greater challenges than improvements. One individual operating an older facility suggested that the many modifications undertaken in the past, leaves little hope of determining how to re-set the system to function as initially designed.

Anecdotal evidence as well a review of slurry mixing literature suggests that removing baffles promotes MgO settling and solids buildup within the tank. The purpose of the baffles is to prevent areas of low movement along the sides of the tank, which leads to MgO dropping out of suspension.

Discussions with suppliers indicate that baffles should be at 1/12 of the tank diameter, or a minimum baffle to tank ratio of 0.083 (Dynamix, 2012). The baffle-to-tank ratio is known for five facilities. Three of these facilities have no issues with solids below liquid level in their slurry mix tank; they have baffle-to-tank diameter ratios of 0.051, 0.087 and 0.083. The facilities that reported some minor issues with slurry tank operation have a baffle-to-tank diameter ratio of 0.091 and 0.11. Tanks with larger baffle-to-tank diameter ratios have issues with plugging while tanks with ratios from 0.087 and lower have fewer issues with solids formation. It is likely that there is a lower threshold as well; however information is insufficient to determine this threshold. A functional tank diameter-to-baffle ratio to specify is 0.083.

Discussions with suppliers also indicated that a space between the baffle and the tank wall of 1/24 of the tank diameter is required for proper mixing (Dynamix, 2012). Only one facility reported a baffle-to-wall space in their slurry mix tank, therefore there is not sufficient information to draw conclusions regarding a space between the baffle and tank wall.

Lastly, suppliers indicated that the inclusion of four baffles is typically required for efficient mixing and use of space in a round tank (Hayward Gordon Ltd, 2000). All of the tanks that had baffles had four baffles. In addition, discussions with the chemical supplier, Baymag, indicated that baffles should be below the normal liquid level to prevent solids buildup on the baffles. There is little evidence to support this in the information analyzed.

Proposed Design Guidelines

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.

Proposed Operational and Maintenance Guideline

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.

6.2.5 Agitator and Mixing

Anecdotal knowledge suggests that larger diameter impellers at lower rotational speeds result in better mixing for MgO slurries than smaller diameter impellers with higher rotational speeds. This knowledge is reinforced by the information collected from individual facilities. Facilities 3 and 12 reported having no issues in their slurry mix tanks, or the issue was unknown; these facilities had impeller to tank diameter ratios of 0.45 and 0.5, respectively. Additionally, they had the lowest mixing speed reported of 107 RPM and 58 RPM.

Facilities 1, 3, 4 and 12 had two impellers, which could potentially lead to more effective mixing. The information collected does not lead to any conclusions that the use of two impellers provides better mixing. Half of the facilities with two impellers had no solids buildup below liquid level while half did have solids buildup below liquid level.

Facilities with smaller agitator to tank ratios such as 0.17 and 0.22 and higher mixing speeds from 370 RPM to 2200 RPM report more issues with tank plugging. Therefore, it is recommended that the agitator impeller diameter should be one third to one half the tank diameter and that the agitator have a low rotating speed.

All facilities that had issues achieving the desired slurry concentration had issues with plugging of the suction nozzle. They all had small impeller agitators (12”, 14”) and the fastest impeller rotation speeds of all facilities of 2200 RPM and 1200-1300 RPM.

See proposed Design Guideline 18 in Section 6.2.1 for recommendations on rotational speeds.

Proposed Design Guidelines

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

The above details should be specified when the agitator and tank go out for competitive bid. If they are not specified, suppliers will likely provide a small diameter agitator impeller with a high rotational speed because this is the cheapest option. Specification of exact agitator type and speed is outside of the scope of this project; however, future work to provide more detailed specifications would benefit companies with plans to install MgO dosing systems.

Three facilities (33.3%) have the agitator entering the slurry mix tank at an angle, while six facilities (66.7%) have the agitator entering the slurry mix tank directly in the centre of the tank. Two of the three facilities that reported the agitator entering the tank at an angle had major ongoing issues with solids formation and plugging in their slurry mix tank. All three of these facilities also reported that they had issues with plugging of the suction line exiting the mix tank. Only two of the six facilities with the agitator directly in the middle of the tank reported issues with suction line plugging. In order to ensure proper mixing it is recommended that the slurry tank agitator enters the tank at the centre. See proposed Design Guideline 18.

6.2.6 Level Measurement

Six facilities noted that level measurement in the slurry mix tank is a challenge. One facility noted that the level measurement is critical to its process, as this affects the water flow makeup rate which in turn affects the slurry strength.

Three facilities used a radar type measurement device, and two of these facility operators noted their measurement device was accurate. One facility reported using a differential pressure measurement device; this device plugged frequently and therefore was not reliable. One facility used an ultrasonic measurement device and three facilities used bubble tube measurement devices; the bubble tube measurement devices required a great deal of maintenance, although less than differential pressure measurement devices.

Three facilities performed preventative maintenance on their slurry mix tank level measurement devices. One with float switches did this on an unknown schedule, and two with bubble tubes did daily water flushes.

According to the above findings the most effective level measurement devices that require the least ongoing maintenance are the radar and the ultrasonic level measurement devices. It should be noted that these devices are subject to false measurements due to dust, therefore proper dust control is required.

One facility operator mentioned that they used redundant radar level measurement and found it very effective.

Proposed Design Guidelines

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 including the following:
    - 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 23 regarding dust control.

6.2.7 Water Inlet to Slurry Mix Tank

In most facilities the water inlet to the slurry mix tank is at the top of the tank above normal liquid level. Eight facilities have the water entering above normal liquid level; two of these have the water coming in on the side of the tank and six have the water coming in on the top of the tank. Five facilities have the water coming into the tank below normal liquid level; four of these have the water coming in on the side while one has the water coming in on the bottom of the tank.

There were no trends identified regarding water injection point. However, the only facility with the inlet at the bottom of the tank is experiencing some success. The agitator at this facility frequently fails, due to agitator design, creating mixing issues but they do not have any plugging issues at the bottom of the tank and do not experience plugging in the suction nozzle exiting the tank. This facility does not report solids formation at the bottom of the tank, although a thicker slurry is present.

Although there is no direct evidence in the information collected, locating the water inlet of the bottom of the tank should reduce splashing causing solids buildup. See proposed Design Guideline 19.

6.2.8 MgO Inlet to Slurry Mix Tank

In all facilities, the MgO powder inlet to the slurry mix tank is at the top of the tank. Eight facilities have the powder inlet in the centre of the tank and four facilities have the powder inlet to the side of the tank. One facility with the powder inlet to the side of the tank reported a large amount of buildup on the baffle below the inlet which led to the removal of a portion of the baffle. The collected information does not show any correlations between MgO inlet location and challenges experienced. However, it is recommended that the MgO powder should be added to the tank as close to the centre 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 Guidelines

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.

6.2.9 Slurry Outlet from Slurry Mix Tank

Very little information was available about the slurry outlet location from the slurry mix tank. All facilities had the slurry outlet at the bottom of the slurry mix tank. Two facility operators mentioned that due to plugging, they had raised the slurry outlet from the tank. This, combined with PMs on the tank and the slurry transfer lines, decreased the amount of plugging in the system. One facility that raised the slurry outlet had raised it to 381 mm (15”) from the bottom of the tank. Other facilities have the slurry outlet at 432 mm (17”) and 508 – 610 mm (20-24”). Raising the slurry mix tank outlet does not address the issue of solids formation in the slurry mix tank, however it does increase operability and it may increase the amount of time available between PMs.

Residence time appears not to have an impact on plugging of suction nozzles, as facilities with both high and low retention times had no issues with this type of plugging.

Proposed Design Guideline

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.

7.0 Slurry Transfer Lines and Feed Pump

The slurry transfer lines and the feed pump downstream of the slurry mix tank present a challenge for many facilities. In the first workshop, this was identified as the major challenge for most facilities. If the slurry velocity does not remain above settling velocity, the lines will plug. Additional challenges with plugging are introduced with the potential formation of calcium carbonate deposits and when recirculation lines are added into the system.

7.1 Results

Table 9 shows the transfer line system details as well as a summary of the challenges that facilities reported with their slurry transfer line systems. In general, the lines have a diameter of 2” (5 cm) or greater. Many of the systems have a combination of hard pipe and hose or hard pipe and flanged flexible pipe. Seven of the facilities have hard pipe, two have flexible pipe, one has flexible flanged pipe and four have hose. The target slurry velocities range from as low as 1.4 m/s to over 3 m/s while the actual velocities range from 0.6 m/s to 3 m/s.

The greatest challenge with the slurry transfer system is line plugging due to settling and scaling, valve erosion and pump plugging. Additionally, some facilities reported excess wear on the slurry transfer pump; however, no facilities reported having to change the impeller on the pump more often than every year.

Table 9. Equipment and challenge matrix – slurry transfer lines and slurry transfer 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
Core equipment	Line Size		1 1/2"	1 1/2" - 3"	2"	3" & 6"	2 & 2 1/2"	1 1/2"	2"	2"	2"	2"	2"	4" & 6"
	Line Type	Hard pipe		X	X		X		X	X	X	X	X	
		Flexible pipe				X[4]								X[4]
		Flanged Flexible Hose					X[3]							
		Hose	X					X				X	X	
	Length of pipe		~30 - 40 m	Unknown	Unknown	Unknown	~60m	40m	> 100 m	> 100 m	Unknown	47 m	122 m	Unknown
Process components and potential causes	Water Quality	Temperature	15-25°C	55°C	40°C	40°C	40°C	40°C	40°C	40°C	35-40°C	40 - 75°C	35°C	40°C
		TOC	280 ppm	Low	Unknown	155 ppm	372 ppm	<5 ppm	550 ppm	560 ppm	165 ppm	260 ppm	150 ppm	162 ppm
		Conductivity	3600 uS/cm	Low	40 uS/cm	12,000 uS/cm	4275 uS/cm	150 uS/cm	10,500 uS/cm	9,500 uS/cm	12,600 us/cm	19,000 uS/cm	19,000 uS/cm	11,100 uS/cm
		Hardness	Unknown	Zero	0.3 ppm	0 ppm	<0.5 ppm	Unknown	<0.5 ppm as CaCO3	<0.5 ppm as CaCO3	<1 ppm	560 ppm	0.4-400 ppm	0 ppm
		Carbonates	270 ppm	Zero	Unknown	Unknown	160 ppm	100 ppm	Unknown	Unknown	216 ppm	Unknown	Unknown	Unknown
		Alkalinity	250 ppm	Low	Unknown	713 ppm	364 ppm	<10 ppm	462 ppm as CaCO3	750 ppm as CaCO3	361 ppm	166 ppm	82	681 ppm
		Oil & Grease	29 ppm	Low	0.5 ppm	12 ppm	15 ppm	Unknown	0.3 ppm	0.2 ppm	0 ppm	Nil	Nil	4.5 ppm
	Slurry Concentration		5%	2-5%	2-5%	2-5%	5-10% (8%)	0.005	Unknown	Unknown	0.03	10% max.	0.06	2-5%
	Velocity	Min. velocity	1.5 m/s	Unknown	2.5 m/s supply 1.6 m/s return	0.6 m/s	Unknown	1.8 m/s	2 m/s	1.4 m/s	3 m/s	> 2 m/s	2.4 m/s	Unknonwn
		Actual velocity	1.5 - 2.6 m/s	Unknown	0.6 m/s	0.6 m/s	Unknown	1.8 m/s	Unknown	Unknown	2.5 – 3 m/s	~0.6 - 0.9 m/s	2.4 m/s	Unknown
	PMs?	Are there PMs?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
		Water Flush (frequency)	N/A		Unknown		N/A	N/A	N/A	N/A	Daily	Daily	Daily	
		Acid Clean (frequency)	N/A	5-6 months	No	3 months	3-4 months	Weekly	1-2 times a year	1-2 times a year	Every couple of years	1-2 months	1-2 months	3 months
	Are there permanent flush lines?		No	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No
		Frequency	N/A	Unknown	Unknown	N/A	Unknown	N/A	Unknown	N/A	Unknown			N/A
		On a timer	N/A		Unknown	N/A	Unknown	N/A	N/A	N/A		30 minutes	Before / After pumping	N/A
	Are recirc lines used?	Used?	No	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes
		For Slurry	N/A	No	Yes	Yes	Yes	N/A	N/A	No				Yes
		For Acid Only	N/A	Yes	Unknown	No	No	N/A	N/A	Yes				No
	Batch										X			
	Continuous with recycle			X6		X	X							X
	Continuous with VFD		X						X	X		X	X	
	Continuous													
	Once through system							X						
	Is there settling at the bottom of the slurry mix tank		Y	N		Y	Y	Yes	Yes	Yes	No			Y
	Height of suction line from bottom of slurry tank		20-24"	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	15"	17"	Unknown
	Type of valves	Pinch				X	X							X
		Plug		X		X			X	X				X
		Ball	X					X[1]			X	X	X	
		Gate									X	X		
		Check	X											
	Valve location[2]	System high point					X							X
		Other location	X	X		X		X	X	X		X	X	
Challenges	Line plugging	Settling	X			X	X	X	X	X		X		
		Scaling	X				X	X	X	X		X		
	Valve erosion		X	X		X		X	X	X	X			X
	Valves / lines leaking													
	Abrasion of pipeline tees		X	X										
	Frequency of wear on pump impeller	6-12 months												
		>12 months (not an issue)				X			X	X	X	X	X	X
		Is an issue - unknown frequency					X	X						
	Plugging of suction nozzles					X	X	X						
	Pump plugging		X			X	X	X	X	X		X		
	Scaling						X	X	X	X				
	Backup pump plugged					X								

Notes:
1. Switched from pinch
2. This is mainly relevant for systems that use slurry recycle lines
3. From Tank to Pump
4. Fibreglass
5. Batch - Full batch system both into slurry mix tank and out of slurry mix tank
6. There is a recycle line, this line is rarely used except for acid.
7. Continuous - Continuous varying MgO flow into slurry mix tank, continuous varying water flowrate into slurry mixtank and continuous constant slurry flow out of tank (with recirc)
8. Once through system - Continuous varying MgO flow into slurry mix tank, continuous constant water flowrate into slurry mixtank and continuous constant slurry flowrate out of tank

7.2 Analysis

The major components of the MgO slurry system downstream of slurry mix tank are the transfer lines, the slurry transfer pump and the valves on the lines. These three components are assessed below.

The major recommendation for system owners is the development of an MgO system piping specification to help manage the challenges unique to this system.

Proposed Design Guideline

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.

7.2.1 Lines

Line plugging was reported by seven of the facilities interviewed (58%). Of these facilities, six reported that plugging was due to both settling and scaling while one reported that it was from settling alone. The facilities that reported scaling attributed this to water chemistry, which is discussed in Section 8.0 of this report.

Facilities reporting line plugging also reported plugging of other elements. Conversely, where line plugging was not reported, there were no reports of plugging of other elements.

Settling generally occurs when the slurry travelling through the slurry transfer lines falls below the settling velocity. Many of the facilities that reported line plugging due to settling did not know the actual velocity of the slurry. The actual velocities ranged from 0.6 m/s to 1.8 m/s, with the exception of one facility that reported a range between 1.5 and 2.6 m/s. This site had the following notable characteristics:

- Hardness 560 mg/L;
- Temperature as high as 75°C; and
- Daily water flushing and acid cleaning every 1 to 2 months, indicating it does not prevent plugging.

The “Valves, Piping, and Pipelines Handbook” by Christopher Dickenson (1999) discusses the settling velocity of particles in slurry suspensions. Settling velocity depends on the size of particle and the concentration. However, approximate flow velocities to maintain different particle sizes in suspension with water are summarized in Table 10.

Table 10. Particle size and settling velocity

Particle Size	Approximate Flow Velocity
Fines (particle size 75 um or less)	0.9 m/s (3 fps)
Sands (particle size 75 um to 850 um)	1.5 m/s (5 fps)
Coarse (particle size 850 um to 5,000 um)	2.1 m/s (7 fps)

Baymag indicated that the typical MgO particle size is up to 75 um or less. Anecdotal evidence suggests that the settling velocity for lime is 2 m/s and the settling velocity for the MgO slurry is likely similar. Confirmed by the information analysis, the MgO velocity should not drop below 2.5 m/s, based on the higher range of a facility that reported plugging.

A review of TOC, alkalinity, and TDS information suggests that these are not as important as velocity. It is believed that this is the single greatest effect on plugging of transfer lines and additional correlations are discussed below.

Proposed Design Guideline

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.

Five facilities used hose for at least a portion of their slurry transfer piping system. Three of the facilities using hose had recently transitioned from the use of hard pipe. All of them observed that the hose plugged less frequently and that it was easier to maintain. One facility that had a mix of hard pipe and hose noted fewer plugging issues with the hose. Most facilities used hose on the suction side of the pump at a minimum, and saw improvement. Another advantage of hose identified by at least two facilities is the fewer valves associated with hose. Typically only isolation valves are used on a hose so there is less potential for valve erosion.

Proposed Design Guidelines

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.

Five of the seven facilities that experienced line plugging operate in a continuous dosing mode with VFD, while two operate continuously with recycle. Operating a VFD may allow for the velocity to fall below the required velocity, or sudden changes in slurry concentration may promote blockage. However, the use of valves for flow control can also be problematic. Many operators experienced valve erosion on control valves downstream of the pump, as discussed in Section 7.2.2.

Two of the three facilities operating continuously with a recirculation line have line plugging issues, but three other facilities with recirculation report no issues. Five facilities indicated they stopped using recirculation because it created velocities in the lines that allowed for settling. See proposed Design Guidelines 39.

Proposed Design Guidelines

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.

The use of recirculation lines adds additional challenges to the operation of the slurry transfer lines as the recirculation lines have potential to cause dead legs where there is no flow, or to decrease the slurry velocity. Six facilities reported using the recirculation lines, four of which used them for slurry recirculation and the other two for acid cleans. Four facilities reported having used recirculation lines in the past but discontinued use due to operability challenges.

Three of the seven facilities with line plugging used recirculation lines, two of them for the slurry and one for acid cleans. However, two facilities that did not experience plugging also used them for slurry, and one facility without plugging only used such lines for acid cleans. Therefore, no correlations can be made between line plugging and recirculation line use.

The following is a summary of the timing of acid cleans for facilities with plugging and without plugging.

- With Plugging
    - Weekly
    - 1 – 2 months
    - 1 – 2 times per year
    - 3 months
    - 3 – 4 months
    - N/A
- Without Plugging
    - None
    - 1 – 2 months
    - 5 – 6 months
    - Every couple of years

Four of the seven facilities (57%) with plugging did not have permanent flush lines. Two of the five facilities without plugging had permanent flush lines which were flushed on a daily basis, while another two only undertook acid cleaning either every three or every five to six months. One facility that flushed with water on a daily basis had plugging issues; this facility also performed acid cleans on a monthly or bimonthly basis.

This analysis indicates that preventative maintenance pipeline flushing with water or acid will not necessarily prevent line plugging. Acid flushing has been reported to be effective in cleaning the line, but not in preventing plugging.

Proposed Operational and Maintenance Guideline

12. Do not allow the slurry to remain still in the pipelines, as this will allow for MgO hydration and solids building causing plugging.

7.2.2 Valves

Valve erosion challenges were reported by eight facilities. Valve types used were pinch valves, plug valves, ball valves, gate valves and check valves. Many of these facilities had recently changed, or were planning to change the valves in their system from pinch valves to either ball valves or plug valves. Valve erosion was typically associated with pinch valves. Two facilities mentioned check valve failure due to scaling.

Proposed Design Guideline

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

One facility of five that uses recirculation lines reported plugging in the line due to valve placement. The valve was at a low point and did not allow gravity drainage in the line. Conversely, two facilities with valves placed at the high point in the system as close to the reactor as possible had no plugging in their lines. The placement of the valve at the high point in the system near the reactor allows the slurry in the recirculation line to drain into the slurry mix tank while it is not being used. In addition, minimizing the distance between the valve and the reactor minimizes plugging in this line when it is not being used.

Proposed Design Guideline

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.

As previously mentioned, facilities that have changed from hard pipe to hose report a reduced number of valves on the hose. This reduces potential issues associated with valve erosion and plugging. In general, fewer valves and instrumentation in the lines reduces the potential chance for erosion and failure.

Proposed Design Guideline

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

7.2.3 Pump

Seven facilities reported plugging of the slurry transfer pump as an issue. Of these facilities, only three had permanent water flush lines into the slurry transfer lines before the pump. However, four out of five of the facilities that did not find pump plugging to be an issue did have permanent water flush lines. The facilities with water flush lines used them before and after pumping, and some facilities operated the flush on a timer. The water flush lines clear the pump before and after use to prevent buildup and plugging.

Proposed Design Guideline

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

One facility reported having a pump as a hot standby and reported a many challenges with plugging of this pump. Most other facilities had standby pumps that were either isolated with valves or disconnected from the system when not in use. These facilities used a water flush on the standby pump before and after use, or after the pump was connected and disconnected. Facilities with standby pumps that were disconnected or isolated did not report issues with plugging of the pump upon start-up.

Proposed Design Guideline

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

Proposed Operational and Maintenance Guideline

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

8.0 Water Quality and Temperature

In theory, water quality significantly affects the performance of the MgO system, causing issues such as foaming and scaling. Hassibi (2009) notes that water with high dissolved solids generally causes excessive foaming during lime slaking, and waters containing over 500 mg/L of sulfates or sulfites are unsuitable for slaking. It is assumed that this also applies for MgO slaking.

A review of facility water quality found no significant correlations with any of the challenges sited by facility operators. Many of these potential correlations are discussed within the component specific sections of the report.

Water temperature also has the potential to create challenges with water vapour and moisture exposure as well as accelerated MgO slurry slaking time. In theory, colder water temperatures lead to higher silica removal efficiency. To attain the highest silica removal efficiency, the MgO must slake in the reactor, and colder temperatures contribute to ensuring this occurs, as seen earlier in Figure 2. See proposed Design Guideline 18 and Section 6.2.1.

The water temperature at the MgO facilities analyzed ranged from as low as 15°C to as high as 75°C with nine out of 11 facilities having a temperature around 40°C. Ten of the facilities expressed issues related to slaking occurring before the reactor such as plugging in the slurry mix tank and transfer lines.

During the interviews two companies noted that at colder temperatures, the MgO tends to drop out of suspension. This is common in slurry mixtures and may be the case with MgO slurry. It is also important to note that at lower temperatures lime precipitates have a greater chance of falling out of suspension. The balance between the potential challenges caused by lime precipitates from cool water and the drowning of lime impurities to make them unreactive requires further investigation.

Proposed Design Guideline

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.

9.0 Dosing and Slurry Concentration Control

There are three general methods of slurry concentration control: the once through method, the batching method and the continuous method, described below. These descriptions focus on the method of slurry control out of the mix tank; some facilities batch the MgO powder into the slurry mix tank and some facilities have a continual flow of MgO powder into the tank.

- Once through method: The water flowrate into the reactor is constant, as is the MgO slurry flowrate out of the reactor, however the amount of MgO powder added to the slurry varies.
- Batching method: The MgO powder and water are batched into the slurry tank and the slurry mixture is batched out of the tank.
- Continuous method: The water flowrate into the slurry mix tank is constant and the MgO powder flowrate into the tank is varied. The slurry flowrate into the downstream reactor is varied by either a pump controlled with a VFD, or a recycle line that allows a portion of the MgO to flow to the reactor and a portion to be recycled back to the slurry mix tank.

9.1 Results

Many operators indicated that managing the slurry concentration and dosing is not an exact science, which makes operating the system a challenge. At the same time, they noted it is not necessary to manage the slurry concentration with a great degree of detail. Making an effort to control the exact MgO to silica ratio in the downstream reactor is not necessarily the most efficient way to run the system.

There were no correlations between the slurry concentration and issues with buildup in the slurry tanks. Nonetheless, there are challenges associated with dosing systems that should be addressed. Table 11 summarizes the information collected on the MgO dosing and slurry concentration control. The table shows the methods of dosing, the relevant process components, and the main challenges reported. The two main challenges were:

- Downstream reactor upsets, and
- Upsets caused by the rotary valve not being addressed prior to an upset in the downstream reactor.

Table 11. Equipment and challenge matrix – MgO 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
Methods	Batching MgO into the slurry mix tank		X	X		X	X				X		
	Batch[2]										X		
	Continuous with recycle[4]			X[3]	X	X	X						
	Continuous with VFD[6]		X						X	X		X	X
	Once through[5]							X					
Process components	Frequency of slurry samples		Unknown	Twice a shift	Twice a Day	4 hours	Frequent	Unknown	3-4 hours	3-4 hours	Weekly8	w smoke break	w smoke break
	Location of slurry samples		Unknown	Prior to reactor	Slurry Mix Tank outlet	Prior to reactor	Slurry return line	In reactor	Test Water After Reactor	Test Water After Reactor	Slurry Mix Tank Outlet	Prior to reactor	Prior to reactor
	Loss-in-weight		X								X		X
	Volumetric			X	X	X	X	X	X	X		X	
	Mechanical component responsible for dosage	Rotary Valve (Volumetric)							X	X			
		Screw Conveyor (Volumetric)	X	X	X	X	X	X			X	X	X
		Volumetric Hopper			X	X						X	
		Loss in weight hopper	X								X		X
	Control basis	Water flow to reactor	X									X	X
		Silica removal after reactor	X	X					X	X			
	Slurry Concentration		5%	2-5%	2-5%	2-5%	5-10% (8%)	0.5%	Unknown	Unknown	3%	10% max.	6%
Challenges	Downstream reactor upsets				X	X	X[1]		X	X		X[1]	
	Upsets caused by rotary valve not addressed prior to upset in downstream reactor								X	X			

Notes:
1. Due to strew conveyor plugging.
2. Batch - Full batch system both into slurry mix tank and out of slurry mix tank
3. There is a recycle line, it is generally only used for acid clean.
4. Continuous with recycle - Continuous varying MgO flow into slurry mix tank, continuous varying water flowrate into slurry mix tank and continuous constant slurry flow out of tank (with recirc)
5. Once through system - Continuous varying MgO flow into slurry mix tank, continuous constant water flowrate into slurry mix tank and continuous constant slurry flowrate out of tank
6. Continuous with VFD - Continuous varying MgO flow into slurry tank, constant water flowrate into slurry mix tank, varies flow out of mix tank (pump on VFD)
7. Testing happens more frequently if there are issues in the system.

9.2 Analysis

The type of dosing system can have an impact on the number of downstream upsets at a facility. All of the facilities have a volumetric MgO control component; either a screw conveyor or a rotary valve.

Three out of 11 facilities (27.3%) use loss-in-weight measurement with screw conveyors to control MgO dosing into the tank. None of these facilities reported downstream reactor upsets.

Eight facilities (72.5%) use a volumetric feeder without loss-in-weight measurement; two use a rotary valve and a screw conveyor. Six of these facilities (75%) reported downstream reactor upsets.

The loss-in-weight measurement along with a volumetric component such as a screw conveyor is more accurate than a volumetric feeder alone. According to the information collected, loss-in-weight measurement leads to fewer downstream reactor upsets. It is therefore recommended that a loss-in-weight measurement device along with a screw conveyor be used to control product dosing.

Proposed Design Guideline

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 8.

Two out of 11 facilities (18.1%) experienced challenges with system upsets caused by rotary valve failure that was not addressed prior to an upset in the downstream reactor. These were the only facilities that used a rotary valve as the mechanical component responsible for dosing the MgO into the slurry mix tank. In addition, both of these facilities noted that this was the biggest operational challenge they had.

It is recommended that the rotary valve should not be used as the primary mechanical component responsible for dosage (see Section 5.2.1). More than one facility suggested that another solution to prevent system upset due to valve failure is the use of an alarm on the rotary valve. The alarm alerts operators when the valve has not moved for a set period of time.

Facilities 5 and 11 noted that upsets in the reactor were due to screw conveyor plugging. Although no facilities used an alarm on the screw conveyor, this could alert operators to screw conveyor failure and would help to mitigate the issue. See Section 5.2.1.

Proposed Design Guideline

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.

There were three different types of slurry sampling techniques. Seven out of 11 facilities (63.6%) sampled the slurry prior to the reactor, one facility (9%) monitored the concentration only in the reactor, and two facilities (18.1%) only sampled the water after the reactor. The facilities that did not take slurry samples prior to the reactor reported that upsets in the reactor were their biggest challenges in operating their slurry system.

However, the frequency of sampling did not appear to improve downstream upsets. The frequency of sampling actually increased with facilities experiencing downstream upsets. This is likely due to a reactive attempt at mitigating upsets. In addition, one facility with a weekly sampling schedule did not have downstream upsets.

Nonetheless, taking slurry samples for a total suspended solids (TSS) test at scheduled intervals enables changes in slurry concentration to be identified and allows operators to manage the change before it has caused problems in the downstream reactor. It is therefore recommended that slurry samples be taken and TSS tests be conducted prior to the reactor.

Proposed Operational and Maintenance Guideline

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.

10.0 Summary of Best Practice Guidelines

The design and operation and maintenance guidelines developed for each key area of interest in the MgO system are listed below in Table 12and

Table 13 respectively with the corresponding section of report where analysis and an explanation of development of the guideline are provided.

Table 12. Summary of Proposed Design Guidelines

Guideline	**Report Section**
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.	4.2.1
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).	4.2.2
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.	4.2.3
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.	4.2.4
MgO Transfer from the Storage Silo to the 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.	5.2
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, and the advantages and disadvantages are outlined below. Do not use a rotary valve as the sole method of MgO powder volume control.	5.2.2

Guideline	Report Section
Advantages and disadvantages of loss-in-weight and volumetric hoppers <table><tr><th colspan="2">Loss-in-weight</th><th colspan="2">Volumetric</th></tr><tr><th>Advantages</th><th>Disadvantages</th><th>Advantages</th><th>Disadvantages</th></tr><tr><td>More accurate MgO volume control</td><td>More expensive</td><td>Less expensive</td><td>Less accurate MgO volume control</td></tr><tr><td>Newer loss-in-weight hoppers have a user friendly interface</td><td>Area must remain dust free, and/or device cleaned regularly (more maintenance required than volumetric hopper)</td><td>Less maintenance required than with a loss-in-weight hopper</td><td>Plugging of level switched creates inconsistent process control</td></tr><tr><td></td><td>Older models are difficult to operate</td><td></td><td></td></tr></table> 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.	
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.	5.2.3
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	5.2.4

Guideline		Report Section
	made of hard pipe, to provide access to detach solids formation buildup in the chute.	
Slurry Mix Tank		
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.	6.2.1
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.	
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.	
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 Design Guidelines 23 to 26 for tank vent system design.	6.2.3
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.	
27.	Include four baffles in the slurry mix tank to promote effective mixing. Baffles should be no higher than the high liquid level	6.2.4

Guideline	Report Section
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.	
29. Size the agitator impeller diameter to be 1/3 to 1/2 of the tank diameter.	6.2.5
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 including the following: • 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 23 regarding dust control.	6.2.6
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.	6.2.8
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.	6.2.9
Slurry Transfer Lines and Feed Pump	
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.	7.2
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.	7.2.1

Guideline	Report Section
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.	
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.	7.2.2
45. Include permanent water flush lines upstream of the pump 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.	7.2.3
Water Quality and Temperature	
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.	8.0
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 8. 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.	9.2

Table 13 - Summary of Proposed Operational and Maintenance Guidelines

Guideline	Report Section
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.	4.2.1
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.	4.2.2
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).	4.2.3
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.	4.2.4
MgO Transfer from the Storage Silo to the Tank	
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	5.2.4
Slurry Mix Tank	
8. Ensure the slurry mix 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.	6.2.3

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.	6.2.4
Slurry Transfer Lines and Feed Pump	
12. Do not allow the slurry to remain still in the pipelines, as this will allow for MgO hydration and solids building causing plugging. 13. Backup pumps should be isolated and flushed before and after use.	7.2.1
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.	9.2

11.0 Conclusions

Upon completion of two workshops, one-on-one interviews, and assessment of twelve thermal enhanced oil recovery facilities, 50 proposed design guidelines and 14 proposed operation and maintenance guidelines were developed.

The major observation from this work 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 design guideline recommendation is for owners to use the guidelines proposed in this report to develop their own specifications for MgO systems.

Many operators have indicated that they will carry these guidelines forward. Doing so in a formal way will ensure that EPC companies are aware of and in a better position to implement these guidelines.

Another major consideration is the understanding of MgO slaking chemistry. A number of challenges are associated with the use of MgO, particularly 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, it can also fall off the tank walls to collect in the bottom of the tank or transfer lines.

For the most efficient silica removal, the hydration of MgO (the slaking reaction), should not occur in the slurry tank and transfer lines but should occur after the slurry reaches the downstream reactor. Lime impurities in the slurry and the impact of temperature on the behaviour of lime are also important, as they can influence scaling in slurry transfer lines.

There were mixed results in examining the relationship with temperature and solids buildup. Nine facilities with water temperatures of approximately 40°C expressed issues related to plugging in the slurry mix tank and transfer lines. One facility with a temperature of 15°C also experienced these issues, and two companies reported that at colder temperatures, the MgO tends to drop out of suspension. This is common in slurry mixtures and may be the case with MgO slurry. The balance between the potential drowning of lime impurities to make them unreactive through reaction with cool water, challenges caused by lime precipitates, and the minimum retention time to prevent slaking of MgO may warrant further investigation. However, Design Guideline 17 is proposed based on the analysis in Section 6.2.1.

In principle, poor water quality should have an impact on solids buildup in the system and scaling. However, no correlations were found between water challenges related to solids or scaling. It is believed that as long as the velocity is high enough, scaling will not create challenges. A velocity of 2.5 m/s is proposed as the ideal slurry flow velocity in the system.

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 true, guideline development was supported with anecdotal evidence and documented literature, as indicated in the analysis.

12.0 Recommendations

A number of issues were raised that, upon further investigation, could advance understanding of MgO system performance. Additional research and discussions in the following areas are recommended:

- Lime Dosing Best Practices
- Additional investigation into specific guidelines:
    - Appropriate size of the tank as a function of the powder addition rate.
    - Type of agitator: Type and number of blades, type and number of impellers, rotational speed
    - Flow control valve type (to best resist erosion)
    - Slurry line plugging (reverse flow direction)
    - Type of silo aeration pads
    - Optimum MgO to silica ratio range for operation.
- Troubleshooting Checklist for Operators
- Basis for Routine Checks and Tests Schedule – shift, daily, weekly
- Monitoring of MgO Systems and Updating Guidelines

Although many of the proposed guidelines could be translated to the lime slurry systems, some unique characteristics of lime systems may warrant further assessment and development of guidelines specific to the lime system. This would provide clarity for operators, engineers and equipment suppliers on the requirements and differences for the two different systems.

There is some interest among the participating companies in continuing the work identified as potential additional investigation topics, as workshop forums as part of technical conferences.

The practical use of these guidelines for operators of existing systems would benefit from a troubleshooting checklist that would enable a quick reference to identify potential solutions to challenged experienced on site. This was outside the scope of this project; however, it would be valuable for operators of existing systems.

Annual updates to these guidelines could be undertaken, based on company monitoring and use of the guidelines. These updates and other future best practice guideline collaborative work will be further pursued by Alberta WaterSMART, as appropriate based on interest from the participating companies.

References

Hassibi, Mohamad. February 2009. An Overview of Lime Slaking and Factors that Affect the Process (Revision 1 of November 1999). Chemco Systems, L.P.

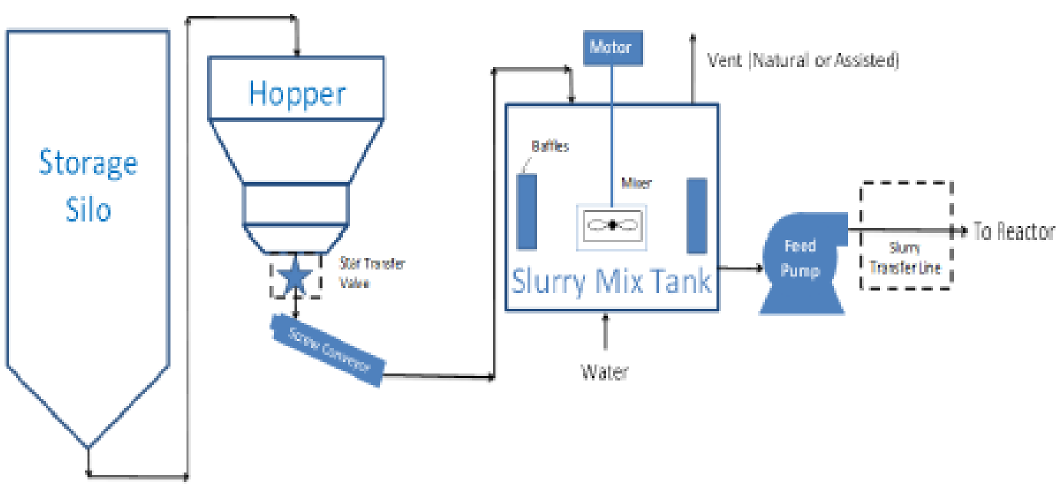
Hayward Gordon Ltd. July 2000. Baffles. (online). Available from: http://www.haywardgordon.com/usercontent/documents/Baffles.pdf (Accessed 20 May 2014).

Dynamix. October 2012. Mixing 101: Baffled by Baffles?. (online). Available from: http://www.dynamixinc.com/baffled-by-baffles (Accessed 20 May 2014).

Appendix 1: Interview Question Guide

MgO Slurry Systems Best Practices
One on One Interview Package

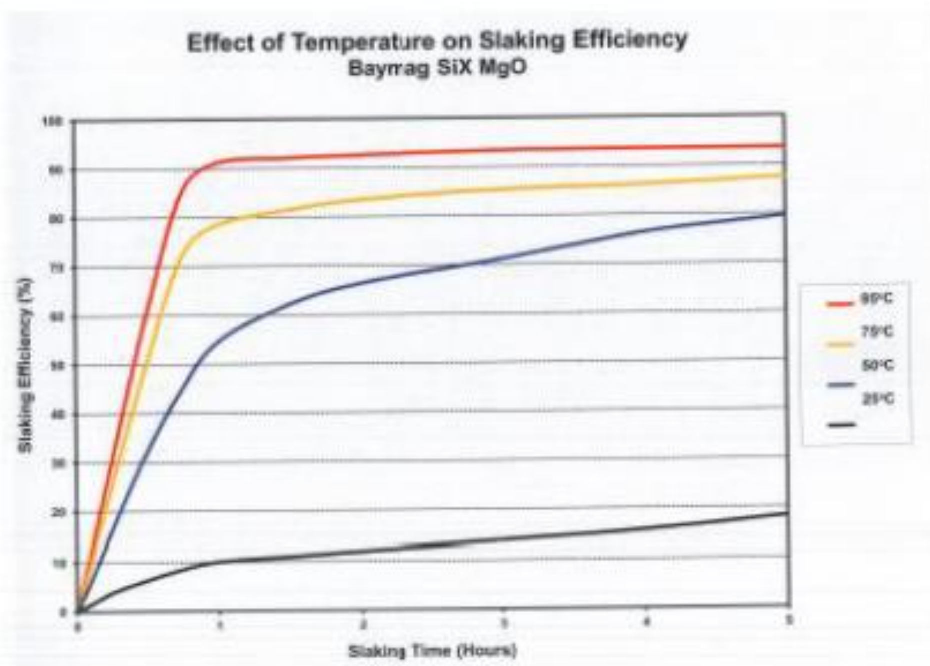
- All of the information collected will not be attributed to the operating companies providing information, or the vendors associated with information collected from vendor drawings, and will eventually be made public. Alberta WaterSMART will use any drawings provided to extract relevant information, but will not publicize the drawings. Owners and suppliers will remain anonymous.
- Please provide the following information at your earliest convenience, as much as possible prior to your interview. A summary of all requested information is attached at the end of the package.
- Please provide a **P&ID with identified flows, and a PFD.** This will help clarify the setup of your particular process and provide context for the discussion. If you have more than two systems, please call Angela (403-210-5287) to discuss which information to provide.
- Please provide **slurry tank and other relevant vendor drawings, and the slurry feed pump curve** for Alberta WaterSMART to extract the information requested.
- We suggest that you provide an **analysis of your makeup water** on the following parameters:
    - Temperature
    - Conductivity
    - TOC
    - Hardness
    - Alkalinity
    - Carbonates (optional)
    - Oil and Grease
- Below is a summary of the challenges and solutions for each process component identified at the workshop on March 5, 2013. Please review these, and the questions that follow each section. We will be asking which challenges you have experienced, which solutions you have employed, and their degree of success.
- We ask that you provide **specific design, operating, and maintenance information related to each component**, as outlined within this package, to analyse and develop correlations between data sets.



1

MgO Slurry System Product Chemistry

- One of the key challenges related to the use of MgO is the build-up of solids on equipment and in transfer lines. Exposure to moisture causes a reaction to occur between the water and MgO powder, which upon hydration that powder becomes very dense. This increase in density makes pumping and transferring the MgO slurry more difficult, and where it creates a solid precipitate, the build-up of solids on equipment and in certain areas can create plugging of system components. The process of MgO hydration is referred to as "slaking". The product does not readily acidize and is therefore difficult to remove from equipment.
- Baymag has provided the slaking curve below which shows the temperature and time to hydration for the Baymag SiX product. Hydration should be avoided until the slurry reaches the downstream reactor, and systems should therefore be designed with low retention times and low water makeup temperatures.



- What is your product designation? i.e. what type of product do you use?

MgO powder storage silo

Challenge	Potential Cause	Potential Solution
Product level measurement and control/management	- Improper measurement of powder level - False reading from dust - Issues with clogging / clumping happening on measurement devices - Operator inexperience, level estimation is difficult for new operators.	- Installation of a cone radar level indicator with air purge - Use of a weight system - Manual measuring - Use of two systems (eg. cone radar & weight) to ensure accuracy
Moisture exposure causes plugging / solids formation	- Moisture from slurry tank	- Installation of a vent system on the slurry mix tank - Use of an air gap - Installation of a scrubber on the air outlet from the slurry mix tank - Installation of an air intake dampener
Inconsistent feed rate of product from the silo	- Feed rate varies depending on head (higher head causes higher feed rate)	
Dust control	- Pressure of transfer of MgO product from delivery mechanism	- Installation of an air purge through or after the rotary / star valve - Installation of a water spray on the mix tank
Bridging over valve	- Moisture from slurry tank	- Installation of an air purge - Installations of impactors or vibrators (on timer) - Installation of overound or spikes

- Has your system experienced any of these challenges or others?
- Are there other causes than those listed above?
- Have you implemented any of the listed solutions or others?
- With what solutions have you had success with? Why?

- What is the dimension of the silo?
- How is the MgO transferred to the silo?
- Who is in charge of product delivery?
- Is temperature controlled in the silo? What temperature?
- Is humidity controlled in the silo? (venting?) What humidity?
- Is pressure controlled in the silo?
- Are any other environmental factors controlled in the silo? (which ones?)
- What preventative maintenance is performed and on what schedule?
- Is the preventative maintenance program successful?

Hopper

Challenge	Potential Cause	Potential Solution
Dust control	- Height of transfer from silo - Pressure of product transfer line into hopper - Location of MgO introduction to hopper	- Minimise gap between hopper and tank (minimise the length of the chute) - Installation of air purge - Add additional access points (there should be two)
Flexible coupling seal failure	- Constant vigorous vibration of the bin activators that transfer product out of the hopper.	-
Inconsistent feed rate of product from the hopper/ challenges in controlling slurry strength	- An on/off gate valve creates inconsistent feed. Over time it will erode and may become jammed with product and not close properly (also likely due to moisture) - Weight scale under the hopper can fail with moisture exposure	- Use of a 8" on/off valve out of the silo and a smaller valve out of the hopper in conjunction with a weighing system on the hopper - Installation of timers on impactors and vibrators to match the process control - Installation of overound and spikes

- Has your system experienced any of these challenges or others?
- What are the causes to your challenge?
- Have you implemented any of the listed solutions or others?
- What solutions have you had success with? Why?

- What are the dimensions of the hopper?
- What other components are there to the hopper?
- How is product transferred to the hopper?
- Does the product transfer create dust?
- To what extent is dust contained?
- How is the dust controlled?
- How is powder transferred out of the hopper?
- What impact does the method of transfer out of the hopper have on the slurry concentration?
- Is temperature controlled in the hopper?
- Is humidity controlled in the hopper?
- Is pressure controlled in the hopper?
- Are there other environmental conditions controlled in the hopper?
- What preventative maintenance is performed and on what schedule?
- Is the preventative maintenance program successful?

Star/Rotary Transfer Valve

*Be sure to clarify where this valve is in the system, if there is one valve or multiple valves, what kind of valves they are, how they are operated and if the valves are used to control slurry concentration.

Challenge	Potential Cause	Potential Solution
Valve erosion issues	- Abrasion	- Material upgrade - Installation of an air purge through the valve
Valve washout	-	- Material upgrade - Installation of an air purge through the valve
Upsets caused by valve failure not addressed prior to upsets in downstream reactor	- Difficulty in sending signal of failure to control room/operators	-
Repeatability of volumetric feeder (does not always feed the same volume / weight)	- Sizing, too large creates challenges for feed rates	- Use of an 8" on/off valve from the silo and a smaller valve for volumetric feed control out of the hopper
Plugging	- Sizing (too small) - Moisture in MgO	- Use a 8" valve at a minimum - Installation of an air purge through the valve - Moisture control in mix tank (see moisture exposure above)
Sizing	- Valve is sometimes too big for volumetric control - Valve is too small causing plugging	- Use of an 8" on/off valve from the silo and a smaller valve for volumetric feed control out of the hopper

- Has your system experienced any of these challenges or others?
- What are the causes to your challenge?
- Have you implemented any of the listed solutions or others?
- What solutions have you had success with? Why?
- Please indicate the following parameters of your system:
    - Size
    - Type
    - Material
    - Control
    - Other key variables to consider

- What preventative maintenance is performed and on what schedule?
- Is the preventative maintenance program successful?

Screw Conveyor

Challenge	Potential Cause	Potential Solution
Loss of product	- Clogging of conveyor due to moisture from slurry tank travelling up to conveyor; may be caused by inadequate venting of slurry tank	- Installation of a low flow air purge - Use of an air gap - Installation of a scrubber on air outlet from tank - Installation of an air intake dampener
Difficulty in achieving low feed rate (creating a need for batch slurry production as opposed to continuous)	- Conveyor is too large or does not have enough variability	- Use of a smaller conveyor
Maintenance to clean out product build up	- Conveyor not easily accessible for maintenance and challenging to take apart to clean	- Add additional clean out ports
Scaling		

- Has your system experienced any of these challenges or others?
- What are the causes to your challenge?
- Have you implemented any of the listed solutions or others?
- What solutions have you had success with? Why?

- Are there issues with solids formation in the screw conveyor?
- Please indicate the following parameters of your system:
    - Size
    - Type
    - Material
    - Control
    - Other variables?

- What preventative maintenance is performed and on what schedule?
- Is the preventative maintenance program successful?

Slurry Mix Tank

Challenge	Potential Cause	Potential Solution
Dust Control	· Height and pressure of incoming product into tank creates dust.	· Installation of a fan on tank vent outlet to a wet scrubber · Water spray to knock out dust particles · Additional regulation of air pressure control in the MgO feed line · Covering the tank (typical)
Vapour accumulation	· Insufficient venting	·
Vent Plugging	· Vent system undersized · Vent is not able to handle moisture and dust without clogging	· Increase size of vent · Should vent outside · Ensure that there is a proper vent design for varied heat, volume and operating conditions · Change location of dry air injection into tank
Achieving desired slurry density	· Tank sizing – typically sized the same as a lime system but only requires approximately 1/3 of the size.	· Solubility of MgO drops with water temperature · Water should be as cold as possible to reduce hydration potential
Build-up of product on baffles, falls to bottom of tank	· Location compared to product introduction, and water feed · Sizing	· Baffles to be installed only below liquid level (below active tank level) · Introduce MgO product into middle of the tank · Minimise dead space
Settling of solids in bottom of tank	· Insufficient mixing · Changing the direction of the agitator can cause issues · Mixing blade not properly sized · Speed of agitator not sufficient · Baffles are typically needed, but are sometimes removed	· Additional modelling may help set up the tank for better mixing · Larger paddle type agitator · Less agitation, more movement to keep solids suspended (keep vortex towards shaft) · Dual stage paddle · Pitch blades with slower mix speed · Use square tank
Downstream reactor upsets	· Absence of online monitoring and metering of slurry and mix tank performance · Plugging of suction nozzles · Plugging of screw feed	·

Challenge	Potential Cause	Potential Solution
Plugging of suction nozzles	- Buildup of product on sides of tanks and accumulation in bottom of tank - Insufficient mixing	- Introduction of water into the bottom of the tank or upstream of suction slurry lines
Plugging and product buildup in screw feeder	- Buildup of product on sides and bottom of tank - Insufficient mixing - Dry material is caked and clumped in air space above slurry due to moisture absorption; this contributes to dust and vapour accumulation	- Introduction of water into the bottom of the tank or upstream of suction slurry lines - Minimise residence time
Tank corrosion	- Product buildup	- Weekly PMs
Slurry tank level measurement (live measurement in not achievable)	- Dust control - Foam build-up	- Use of radar level indicators - Bubble tubes - Float/rods - Ultrasonic
Foaming	- Water quality (organics)	- Water spray nozzle to dampen foam - Change makeup water - Examination of turbulence vs. aeration
Limited capacity to conduct performance maintenance	- All of the above challenges – what is the challenge that creates the most maintenance	-

- Has your system experienced any of these challenges or others?
- What are the causes to your challenge?
- Have you implemented any of the listed solutions or others?
- What solutions have you had success with? Why?

- Where does water come into the tank?
- Where does MgO come into the tank?
- How do you control your MgO to water ratio?
- Does the MgO:water ratio control work well? Why/why not?
- What is the slurry concentration goal?
- How is the slurry concentration measured or ensured?
- What type of vent /wet scrubber do you use?
- How does the vent/wet scrubber perform?
- How do you control moisture from the tank?
- Is the moisture control in the tank successful with reducing moisture within other components?
- Please indicate the following parameters of your system:
    - Number of baffles
    - Baffle dimensions
    - Baffle location/arrangement

- Agitator impeller type
- Agitator impeller size
- Agitator impeller speed
- Is the agitator impeller shaft in the middle of the tank or off to the side?
- In what direction does the agitator mix the slurry? Toward the bottom? Toward the middle?
- What is the distance from the liquid level to the impeller(s)?
- How often must solids buildup be removed from the wall?
- If there is solids build up, is it caused by splashing, or high humidity and dust, or both?
- What are the slurry tank dimensions?
- What is the normal liquid level from in the tank (from the bottom)?
- What is the normal liquid level from bottom of tank and in relation to other equipment?
- What is the design tank residence time (from mix tank to injection point)?
- What do you think the actual residence time is?
- Is the temperature controlled in the tank? What temperature?
- Is humidity controlled in the tank? (venting) What humidity?
- Is pressure controlled in the tank? What pressure?
- Are any other environmental conditions controlled in the tank? Which ones?

- Raw water quality (please provide water analysis if possible)
  - Temperature
  - Conductivity
  - TOC
  - Hardness
  - Alkalinity
  - Carbonates (optional)
  - Oil and Grease

- What preventative maintenance is performed and on what schedule?
- Is the preventative maintenance program successful?

Slurry Feed Pump

Challenge	Potential Cause	Potential Solution
Wear on impeller (replace every 6 – 12 months)	· Impeller material – pumps are handling coarse material, the service is relatively harsh	· Use oversized pump on VFD · Vary the type of pump
Plugged with solids	· Solids come through from the bottom of the mixing tank	· Locate gauges on either end of the pump, use to monitor suction pressure
Scaling – maintenance every 1 – 2 weeks	· May be caused by the quality of the make-up water	· Chemical cleaner
Hot standby (backup pump) is often plugged and not available for backup	· Settling of solids and clumps of product on bottom of tank	· Separate / replaceable hose used for suction piping · Straight run with minimal length from tank to pump · Make-up water into suction line · Implementation of a flushing procedure

- Has your system experienced any of these challenges or others?
- What are the causes to your challenge?
- Have you implemented any of the listed solutions or others?
- What solutions have you had success with? Why?

- Please indicate the following parameters of your system:
  - Type
  - Pump size
  - Impeller size
  - Impeller speed
  - Is the pump on a VFD?
  - Other variables?

- What preventative maintenance is performed and on what schedule?
- Is the preventative maintenance program successful?

Slurry Transfer Lines & Recycle Line

Challenge	Potential Cause	Potential Solution
Valve erosion	· Abrasion	· Avoid pinch valves, use plug valves instead · Ensure that valves are at high point in the system
Recirculation lines, valves and diaphragms rip and leak	·	·
Abrasion on piping elbows and tees	· Abrasive hydroxides contribute to erosion in hard pipes, including pin holes · Water quality can be an issue if it is not "good water" · Difficult to access and maintain piping	· Minimise elbows – use long radius elbows · Minimise distance, keep the system components as close together as possible
Upkeep of lines	· Hard pipes are difficult to replace · Difficult to access so cleaning not occurring	· Minimise use of hard pipes, quick disconnect flexible tubing/hoses can be switched and cleaned easily · Install multiple clean-out connections · Ensure consistency in sizing of pipe / hose · Ensure an efficient flow design
Transfer line plugging – settling	· Low velocities · Settling in pipe, especially at elbow, · Once crystallization occurs it continues rapidly · No preventative flushing	· Maintain velocity (>2 m/s) with use of different pumps · Use lowest possible alkalinity water · Implement a flushing procedure (PM) · Avoid use of hard pipe, · Minimise the number of bends (use long radius elbows) and large slopes · Consider having a separate or twinned slurry piping system
Transfer line plugging – scaling	· Build up/scaling (occurs quarterly to weekly) · Water quality	· Chemical scale inhibitor (is there an optimal injection location?) · Use lower alkalinity water · Use coldest water possible

- Has your system experienced any of these challenges or others?
- What are the causes to your challenge?
- Have you implemented any of the listed solutions or others?
- What solutions have you had success with? Why?

- Please indicate the following parameters of your system:
  - Pipe material and schedule
  - Pipe size
  - Pipe Length
  - How many t's and elbows are in the pipe?
  - What is the pipe slope?

  - Are 90 degrees elbows long or short range?
  - Valve type
  - Valve size(s)
  - Slurry concentration/density
  - Target slurry velocity
  - Actual slurry velocity
  - Location of feed to downstream reactor
  - Is the flow monitored and controlled? How?
- What preventative maintenance is performed and on what schedule?
- Is the preventative maintenance program successful?

Summary of Information Requests

Please provide the following in order to provide the information requests below:

- P&IDs with flows identified
- PFD
- Slurry mix tank vendor drawing and any other relevant vendor drawings with the information below
- Slurry feed pump curve

Component	Information Request	Answer
MgO Product	Where is the product obtained?	
	What is the product designation/type?	
Raw Water Quality	What are the associated challenges?	
	Temperature	
	TOC	
	Conductivity	
	Alkalinity	
	Hardness	
	Carbonates	
	Hydrocarbons	
MgO Powder Silo	What are the associated challenges?	
	What are the dimensions of the silo?	
	How is the MgO transferred to the silo?	
	Who is in charge of product delivery?	
	Is temperature controlled in the silo?	
	Is humidity controlled in the silo? (e.g. venting)	
	Is pressure controlled in the silo?	
	Are any other environmental factors controlled in the silo? (which ones?)	
	What preventative maintenance is performed and on what schedule?	
	Is the preventative maintenance program successful?	
MgO Hopper	What are the associated challenges?	
	What are the dimensions of the hopper?	
	What other components are there to the hopper?	
	How is the product transferred to the hopper?	
	Does the product transfer create dust?	
	How is the dust controlled?	
	How is the powder transferred out of the hopper?	

Component	Information Request	Answer
MgO Hopper (cont'd)	What impact does the method of transfer out of the hopper have on the slurry concentration?	
	Is temperature controlled in the hopper?	
	Is humidity controlled in the silo? (e.g. venting)	
	Is pressure controlled in the hopper?	
	Are any other environmental factors controlled in the hopper? (which ones?)	
	What preventative maintenance is performed and on what schedule?	
	Is the preventative maintenance program successful?	
Star Transfer (Rotary) Valve	What are the associated challenges?	
	Are there any issues with the star transfer valve?	
	What size is the valve?	
	What type of valve is used?	
	What material is the valve?	
	How is the valve controlled?	
	What preventative maintenance is performed and on what schedule?	
	Is the preventative maintenance program successful?	
Screw Conveyor	What are the associated challenges?	
	Are there issues with solids formation in the screw conveyor?	
	What size is the screw conveyor?	
	What type of screw conveyor is used?	
	What material is the screw conveyor?	
	How is the screw conveyor controlled?	
	What preventative maintenance is performed and on what schedule?	
	Is the preventative maintenance program successful?	
Slurry Mix Tank	What are the associated challenges?	
	Where does the MgO come into the tank?	
	Where does the water come into the tank?	
	How do you control the MgO to water ratio?	
	Does the MgO : water ratio control work well? (why?/why not?)	
	What is the slurry concentration goal?	
	How is the slurry concentration measured or ensured?	

Component	Information Request	Answer
Slurry Mix Tank (cont'd)	What time of vent &/ wet scrubber is used?	
	How does the vent &/scrubber perform?	
	How do you control moisture in the tank?	
	Is the moisture control in the tank successful with reducing moisture within other components?	
	How many baffles are there?	
	Where are the baffles located?	
	What are the baffle dimensions?	
	Are there varying numbers of baffles?	
	What size is the agitator impeller(s)?	
	What is the agitator impeller type?	
	What is the speed of the agitator impeller(s)?	
	In what direction does the agitator mix the slurry? Toward the bottom? Toward the middle?	
	What is the distance from the liquid level to the impeller(s)?	
	How often must solids buildup be removed from the wall?	
	If there is solids buildup, is it caused by splashing, high humidity and dust, or both?	
	What are the slurry tank dimensions?	
	What is the normal liquid level in the tank (From the bottom)?	
	What is the normal liquid level in relation to other equipment?	
	What is the planned tank residence time (from mix tank to injection point)?	
	What is do you think the actual residence time is? (from mix tank to injection point)	
	What is the tank maintenance schedule?	
	Is temperature controlled in the tank?	
	Is humidity controlled in the tank? (e.g. venting)	
	Is pressure controlled in the tank?	
	Are any other environmental factors controlled in the tank? (which ones?)	
	What preventative maintenance is performed and on what schedule?	
	Is the preventative maintenance program successful?	
Feed Pump	What are the associated challenges?	
	What type of pump is the feed pump?	
	What is the pump size?	

Component	Information Request	Answer
Feed Pump (cont'd)	What is the impeller size?	
	What is the impeller speed?	
	Is the pump on a VFD?	
	What is the pump maintenance schedule?	
	What preventative maintenance is performed and on what schedule?	
	Is the preventative maintenance program successful?	
Slurry Transfer Lines & Recycle Line	What are the associated challenges?	
	What is the material and schedule of the pipe?	
	What is the size of the pipe?	
	What is the length of the pipe?	
	What type of valves are used?	
	What size of valves are used?	
	How many t's and elbows are in the pipe? SR or LR 90s	
	What is the slurry concentration and density?	
	What is the target slurry velocity?	
	Is the actual slurry velocity known?	
	Is the flow monitored and controlled? How?	
	What is the pipe maintenance schedule?	
	What preventative maintenance is performed and on what schedule?	
	Is the preventative maintenance program successful?	

Appendix 2: Ensuring Successful Use of Guided-Wave Radar Level Measurement Technology

Ensuring Successful Use of Guided-Wave Radar Level Measurement Technology

By Joseph D. Lewis

Guided-wave radar and time domain reflectometry (TDR) have become increasingly popular for measuring the level of powders and bulk solids in bins and silos. Its use is growing at an estimated rate of 12–15% per year, and the size of the worldwide market for guided-wave radar level measurement devices is estimated to be nearly $65 million, with about $25 million being in solids measurement. This means that more than 13,000 units are sold for use in powder and bulk solids applications every year, and that number is growing.[1] There is a good reason for the technology's increasing use and popularity: it works. However, a few tips will enable users to start up and apply the instrument successfully.

How Guided-Wave Radar Began and How It Works

Guided-wave-radar continuous-level sensors typically use TDR technology. This technology was pioneered in the first half of the 20th century for use in geological applications and later was used to detect cable breaks. In the 1990s, TDR was applied as a means for measuring the level of material in a vessel. In less than two decades, TDR and guided-wave radar have become mainstays for measuring the levels of solids and liquids.

In order to identify and explain the key issues that must be properly addressed to ensure successful use of a guided-wave-radar level sensor in a bulk solids application, it is necessary to illustrate how the technology works.

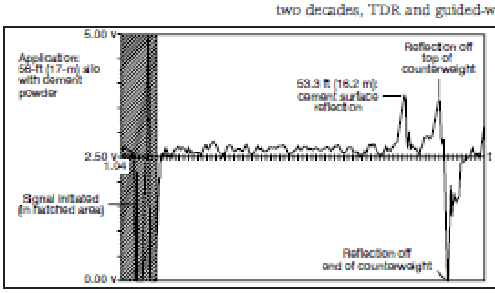


Figure 1: Guided-wave-radar sensor signal in cement application

The level sensor consists of a set of electronics and a probe element. The probe element is called the waveguide. The electronics continuously generate microwave/radar pulses that are transmitted down the probe. The frequency of the pulses is on the low-end of the radar or microwave spectrum—about 1 GHz. These low-power electromagnetic pulses are 1 ns in width.

Because the radar energy is guided to the material surface by the waveguide, the energy is focused and not dispersed into the air, unlike open-air (radar or sonic-type) devices. The size of the energy field sur-

Material	Dielectric Constant (ϵ_r)	Bulk Density (lb/cu ft)
Air	1.0	0
Almonds, shelled	9.0	30–35
Asphalt, liquid	2.5	65
Baking soda	5.7	70–80
Coffee beans, roasted	1.9	22–40
Calcium carbonate	9.1	75
Carbon black, powder	1.4–6.0	4–25
Cement powder	1.5–2.5	85–95
Clinker	2.7	75–90
Corn, whole	5.0	45
Diesel fuel	1.8	52
Ethanol	24.3	56
Flour, wheat	5.0	30–35
Fly ash	1.9–2.6	35–45
HDPE	1.6	35–40
Lime, quicklime	4.8	25–30
Milk powder	1.7	15–20
Nylon	4.0	35–45
Paraffin wax	2.1	45
Polystyrene, expanded beads	2.2	1.5
Potash	5.6	50–60
PVC	1.8	48–52

Table I: Examples of material dielectric constants. Results can vary.

rounding the waveguide or probe depends on the type of waveguide used, which is based on the specific application. This energy field can be as small as 1 in. in diameter or up to about 24 in. in diameter around the probe waveguide. In applications involving powders and granular materials, a single heavy-duty stainless-steel cable is typically used as the waveguide. These cable probes are as large as 0.31 in. in diameter and can handle traction loads up to nearly 4 tons, which is important for solids applications.

Figure 1 illustrates the level of cement powder in a silo measured using a 56-ft cable probe with a 0.31-in. diameter. The installation was good and the signal clean. Radar energy pulses travel at the speed of light along the waveguide. Upon reaching the material surface, the pulses are reflected back with an intensity that depends on the dielectric constant, ϵ_r, of the material being measured. If the material ϵ_r is 2.0, approximately 2.0% of the energy will be reflected. While approximately 80% of the energy is reflected from the surface of water ($\epsilon_r = 80$), granular plastics with dielectrics of 1.6 reflect only 1.6% of the energy. Dielectric constant values for some typical bulk solids are shown in Table I.

When the reflected pulses return, the guided-wave-radar sensor measures the time of flight between the emission and reception of the pulse signals. Half of the time measured is related to the distance of the instrument mounting point to the material surface. The difference between the vessel height and the measured distance is the level of the material in the vessel.

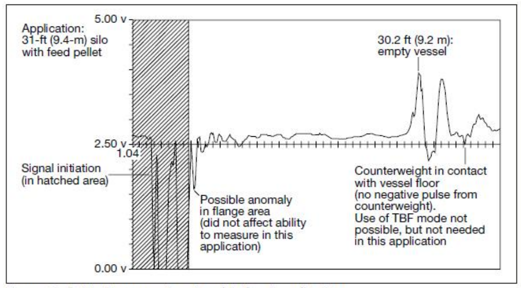


Figure 2: Guided-wave-radar signal in feed application.

Measurements using TDR are not influenced by dust. This is a particularly important feature of the technology when powders are measured, especially during filling with pneumatic conveying systems, In addition, TDR is not influenced by temperature, pressure, or density variations.

Ensuring Success

In addition to following supplier recommendations, users of guided-wave-radar technology

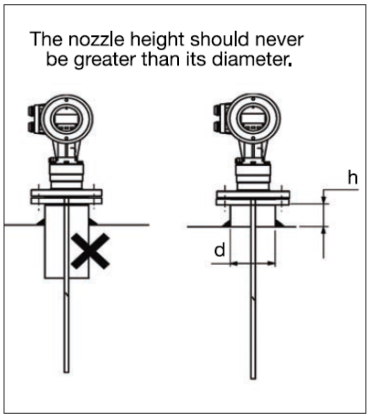


Figure 3: Mounting nozzle, which can be used if necessary but should be avoided if possible. The nozzle height should never be greater than its diameter.

should consider the following four topics to ensure its successful use in measuring powder or bulk solid materials.

Dielectric Constant/Measuring Range. Dielectric constant and measuring range are interdependent. The lower the ϵ_r of the target material, the more challenging the application becomes. The higher the measuring range, the more challenging. The exact relationship depends on the brand and implementation of TDR technology in the level sensor. Therefore, users should consult with a reliable supplier.

Materials that are shown to have ϵ_r values <2.0 do not necessarily generate the signal strength in the reflected pulses to allow the sensor electronics to receive and process it. However, in some units, the signal threshold can be adjusted so that ranges of several meters can be measured with ϵ_r values down to 1.6. Table II presents examples of the relationship between ϵ_r and range. Some manufacturers have developed a modified version of TDR technology known as tank-bottom-following (TBF), which is used in applications in which the dielectric constant of the target material is <2.0.

Tech Tip no. 1: It is important for users in this area to have an accurate and known ϵ_r value for the material to be measured. This enables manufacturers to provide presale application advice based on the material and range, as well as the manufacturers' technology and product. Reliable manufacturers will request samples of low-dielectric or questionable materials so that they can determine their ϵ_r.

Respecting the Electromagnetic Field. Any item that may come within the electromagnetic field of the radar pulses can affect the success of the measurement. Obstructions can present "parasite" reflections. Mounting nozzles or obstructions on the underside of the roof, when they are within the electromagnetic field, can absorb energy and weaken reflected signal strength. They can also present parasitic reflections that may be greater than the reflection off the material surface. The lower the ϵ_r and the greater the distance, the lower the signal strength of the reflection. Obstructions within the electromagnetic field, from the mounting to the probe end, can affect the dielectric constant and range that can be measured.

Tech Tip no. 2: Users should ensure that the mounting method and location will not obstruct the electromagnetic field along the entire length of the probe, from the mounting to the end of the counterweight at the bottom of the probe.

Selecting the Optimal Mounting Location. When considering the optimal

Material	Dielectric Constant (ϵ_r)	Typical Range (m/ft)
Almonds, shelled	9.0	30+/100+
Asphalt, liquid	2.5	30+/100+
Baking soda	5.7	30+/100+
Coffee beans, roasted	1.9	12/40
Calcium carbonate	9.1	30+/100+
Carbon black, powder	1.4–6.0	0–30+/0–100+
Cement powder	1.5–2.5	0–30+/0–100+
Clinker	2.7	30+/100+
Corn, whole	5.0	30+/100+
Diesel fuel	1.8	12/40
Ethanol	24.3	30+/100+
Flour, wheat	5.0	30+/100+
Fly ash	1.9–2.6	12–30+/40–100+
HDPE	1.6	6/20
Lime, quicklime	4.8	30+/100+
Milk powder	1.7	10/33
Nylon	4.0	30+/100+
Paraffin wax	2.1	30+/100+
Polystyrene, expanded beads	2.2	30+/100+
Potash	5.6	30+/100+
PVC	1.8	12/40

Table II: Examples of material dielectric constants and measuring range. The data do not include measuring capability using the TBF method. Results can vary from brand to brand.

mounting location for a continuous-level sensor, the following factors should be considered:

- Angle of repose.
- The desired measuring range.
- Vessel dimensions.
- Internal obstructions.
- Mounting on roof.
- The location of the fill inlet.

Wikipedia defines the angle of repose as an engineering property of granular materials. When bulk granular materials are poured onto a horizontal surface, a conical pile forms. The angle between the surface of the pile and the horizontal surface is known as the angle of repose and is related to the density, surface area, and coefficient of friction of the material. Material with a low angle of repose forms flatter piles than material with a high angle of repose. It is also important to note that materials have a positive and a negative angle. That is, the angle is positive during filling but decreases and becomes negative at some point during discharge.

Tech Tip no. 3: Users should choose a mounting location for the guided-wave-radar level sensor that creates a net-zero effect in regard to the angle of repose. In a cylindrical vessel with center fill and discharge, this location is one-sixth of the diameter from the edge of the vessel. However, it is important to consider the effect of discharging material from the vessel on moving the sensor probe. Even if the effect is slight, users must ensure that the cable probe does not contact the vessel wall (while respecting the electromagnetic field). If needed, users may choose a sensor location slightly closer to the center of the vessel, but anything closer than one-half the radius of the cylindrical vessel is unadvisable. It is also necessary to ensure that the sensor mounting location does not cause internal obstructions to be within the electromagnetic field.

The measuring range and the roof structure itself should also be considered. Ideally, the probe length should be sized to maximize the measuring range, while keeping the end of the probe counterweight off of the cone or vessel wall. The amount of separation needed may depend on the specific technology in question. Figure 2 illustrates the effect on the signal when the counterweight contacts the vessel cone wall. This effect excludes the use of a TBF measuring method that might be needed for very-low-dielectric materials (<2.0; range dependent).

The roof structure should be strong enough to withstand the anticipated traction loading on the probe, which is based on the material density, the probe length, vessel dimensions, and mounting location. While users themselves must decide how strong the roof structure should be, they can learn the basic guidelines from the supplier. For example, a 33-ft silo with cement powder and a guided-wave radar level sensor with 0.31-in. diameter cable probe produces approximately 1800 lb of traction load on the cable probe during discharge of a full vessel. A load of less than 1 ton is far less than the capacity of the cable probe.

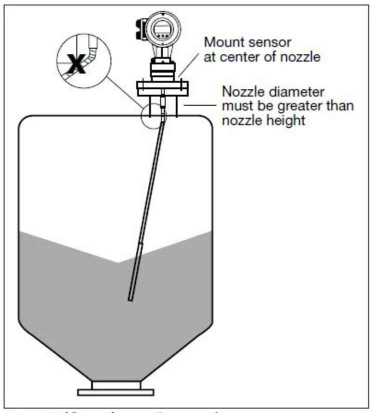


Figure 4: View of mounting nozzle

Tech Tip no. 4: The sensor mounting location will be affected by the fill stream, which is based on the fill inlet location. The sensor should not be installed so that the sensor probe will be in the path of the incoming material. A location as far from the fill inlet as possible should be chosen, although the other sensor location issues should be optimized.

Sensor Mounting. The method for mounting the sensor to the roof of the vessel can determine the difference between success and failure. Users should pay careful attention to this issue in the supplier's installation and operation manual.

Tech Tip no. 5: Whenever possible users should avoid employing mounting nozzles. Figures 3 and 4 present examples of typical mounting-nozzle installations. The ideal mounting method is to mount guided-wave radar sensors plumb, directly inserting them into a welded coupling on top of the silo. Alternatively, an angled or flat mounting flange can be directly mounted to the vessel roof without a nozzle.

If a mounting nozzle of some type must be used (as in the case of a domed roof), the internal diameter of the nozzle must be greater than the height of the nozzle. For a given nozzle height, the greater the diameter, the better. The sensor probe must always be mounted in the center of the nozzle, which eliminates the possibility that the cable probe will become shorted on the nozzle edge during filling or discharge.

The vast majority of guided-wave radar installations are completed without any problem. Eliminating the mounting nozzle or ensuring that it is appropriately sized can resolve 80% of the installation and start-up problems that arise with guided-wave radar units. The remaining installation issues can be addressed by eliminating obstructions within the electromagnetic field or by selecting the proper mounting location.

Conclusion

The demand for guided-wave radar devices has never been higher, and it is growing rapidly. The reasons are simple. The sensors are accurate, reliable under heavy dust conditions (even during filling), and cost-effective (approximately $1800–$2000 on average).

When manufacturers' installation guides and the tips offered in this article are followed, most powder and bulk solids applications will benefit from the use of these sensors. Guided-wave radar technologies have fast become plug-and-play devices, offering greater reliability than other technologies, especially in powders with dielectric constants of ≥2.0. However, even lower-dielectric materials can be measured. For more information, search the Level Measurement blog at www.monitortech.typepad.com.

[1] Market data based on research performed in 2000 by Venture Development Corp. (Natick, MA) for the U.S. Process Level Measurement market.

Joseph D. Lewis is vice president of marketing and sales at Monitor Technologies (Elburn, IL). The company specializes in level measurement and inventory management. For information about guided-wave radar or the company's offerings, call 800-601-6302 or visit www.monitortech.com.

MONITOR

44W320 Keslinger Road ▼ P.O. Box 8048 ▼ Elburn, IL 60119-8048 ▼ 800-766-6486 ▼ 630-365-9403 ▼ Fax 630-365-5646
www.flexar.info ▼ www.monitortech.com ▼ monitor@monitortech.com