A SunCam online continuing education course

Clarifier Rehabilitation

by

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Course Outline:

Overview

Clarifiers are sedimentation tanks with mechanical equipment for the continuous removal of solids. They are the simplest way to treat water and wastewater, which exclaims why they are so common. Most water treatment plants (WTPs) and wastewater treatment plants (WWTPs) have at least one clarifier.

Many of the clarifiers in use today were installed more than 30 years ago and equipment is at the end of the useful life. Owners must decide whether to rehabilitate the clarifiers, replace them with new clarifiers, or change to a different treatment technology. And to help accomplish this, they turn to Engineers such as yourself.

Wastewater Clarifiers

The basic functions of a clarifier are shown in Figure 1. Influent (green arrows) enters the center well and distributes radially throughout the clarifier. The suspended solids (brown arrows) slowly settle to the flow and are pulled from the bottom through a sludge hopper. Floating particles and objects are known as scum (yellow arrows). The clarified effluent is called supernatant (blue arrows).

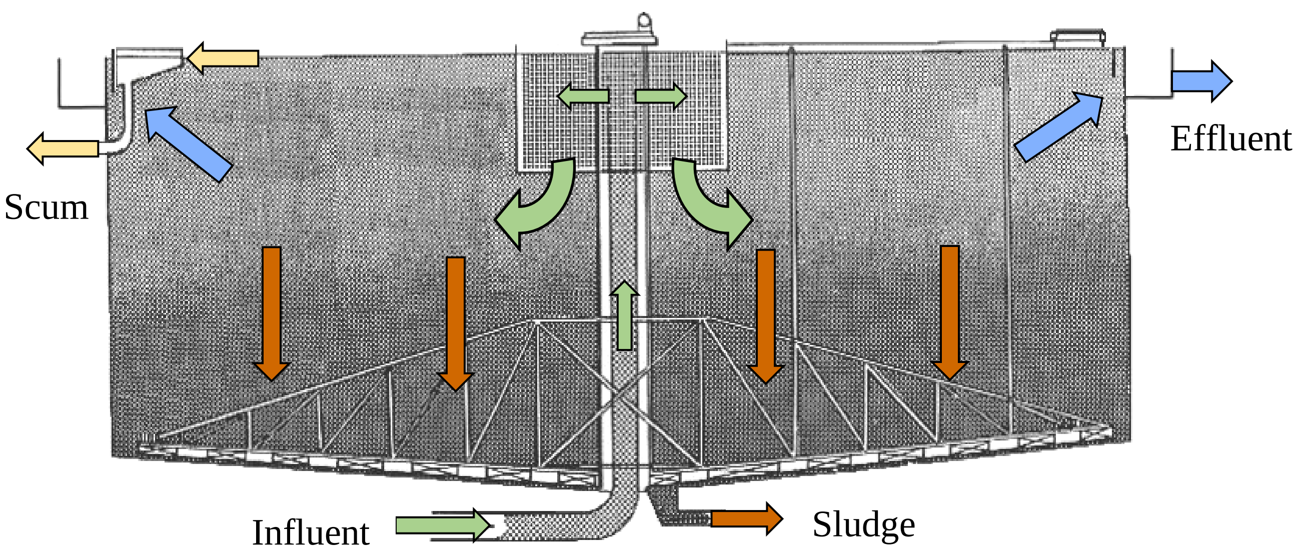


Figure 1: Flows in and out of a typical circular clarifier.

Figure 2 shows the typical components of a circular clarifier. The suction header on the right (labeled tow-bro header) is for collecting activated sludge in a secondary clarifier (a clarifier downstream of an aeration basin). For primary clarifiers, the sludge is heavier and can be collected with scraper blades instead of suction headers. There are numerous variations in clarifier equipment. When considering rehabilitation, the Engineer should review the details of the actual installation.

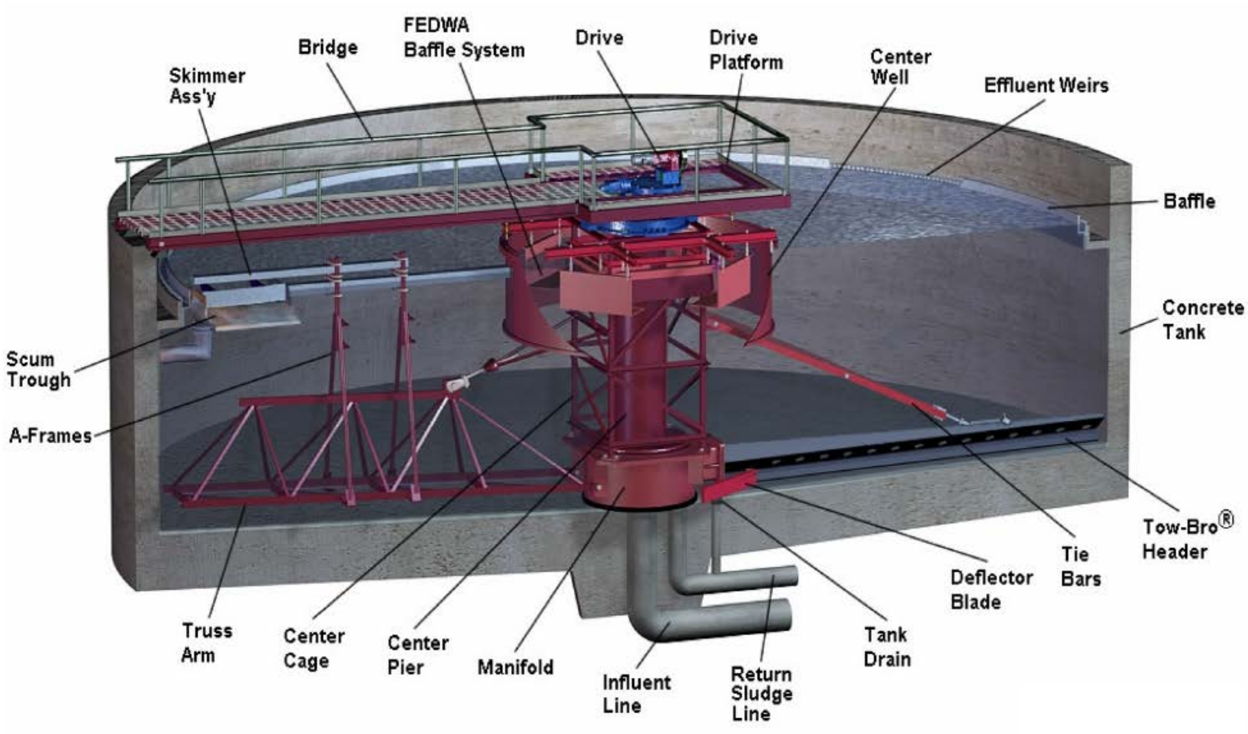


Figure 2: Typical components of a circular clarifier.
Source: Evoqua Water Technologies

See the following figures for examples of circular clarifiers.

Figure 3: Six circular secondary clarifiers at a large WWTP. The large aeration basins (at the bottom of the image) discharge mixed liquor suspended solids (MLSS) to the six clarifiers by gravity.

Figure 4: Internal components of a large circular secondary clarifier. In this case, all submerged components are stainless steel.

Figure 5: A very small circular clarifier.

In addition to primary and secondary treatment, circular clarifiers are often used for thickening of solids. These clarifiers are called gravity thickeners. Gravity thickeners typically include the same components as other circular clarifiers, with the addition of pickets on the sludge collection arms to help release trapped air in the sludge.

Another type of wastewater clarifier is a rectangular clarifier, as shown in Figures 6 and 7. The rectangular shape allows for constructing several clarifiers in a single concrete structure with a smaller footprint than circular clarifiers. Rectangular clarifiers have chain and flight type sludge collection mechanisms.

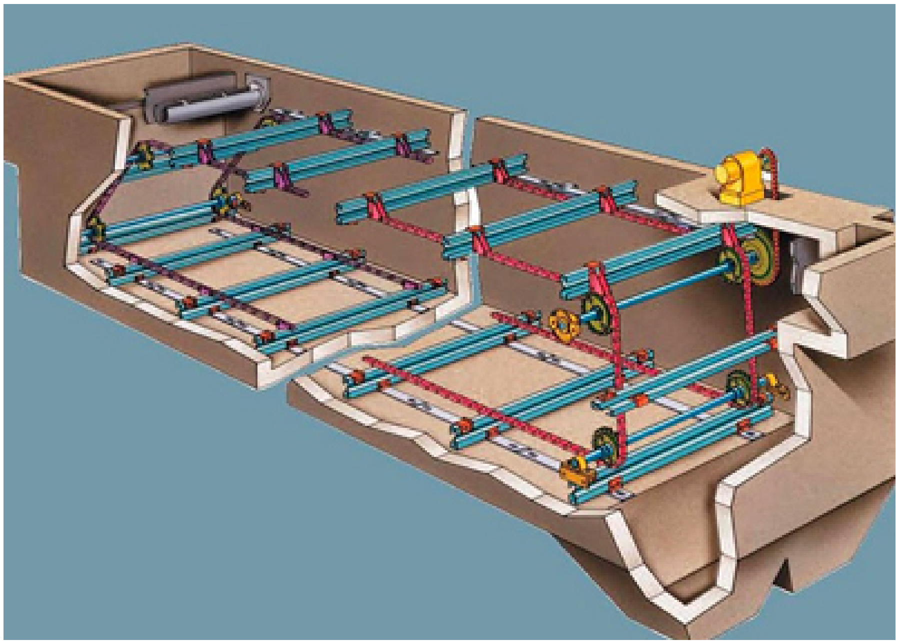


Figure 6: Rectangular clarifier components, including the chain (red), flights (blue), drive (yellow), sprockets (orange), and scum pipe (grey). The depressed chamber on the lower right is the sludge hopper.

Figure 7: Rectangular clarifiers with effluent troughs.

Water Clarifiers

Clarifiers are also used for treating drinking water. The most common application is lime softening. Lime softening is achieved by feeding calcium hydroxide (lime) to the raw water and then removing the settled calcium and magnesium ions. This process can be done with solids contact clarifiers.

Solids contact clarifiers combine three processes in a single tank: 1) mixing, 2) flocculation, and 3) sedimentation. Flow enters into an initial mixing zone in the center, then a flocculation zone in which the lime is introduced, and then an outer sedimentation zone in which settled sludge is removed at the bottom and clarified water leaves at the top. See Figures 9 and 10 for examples.

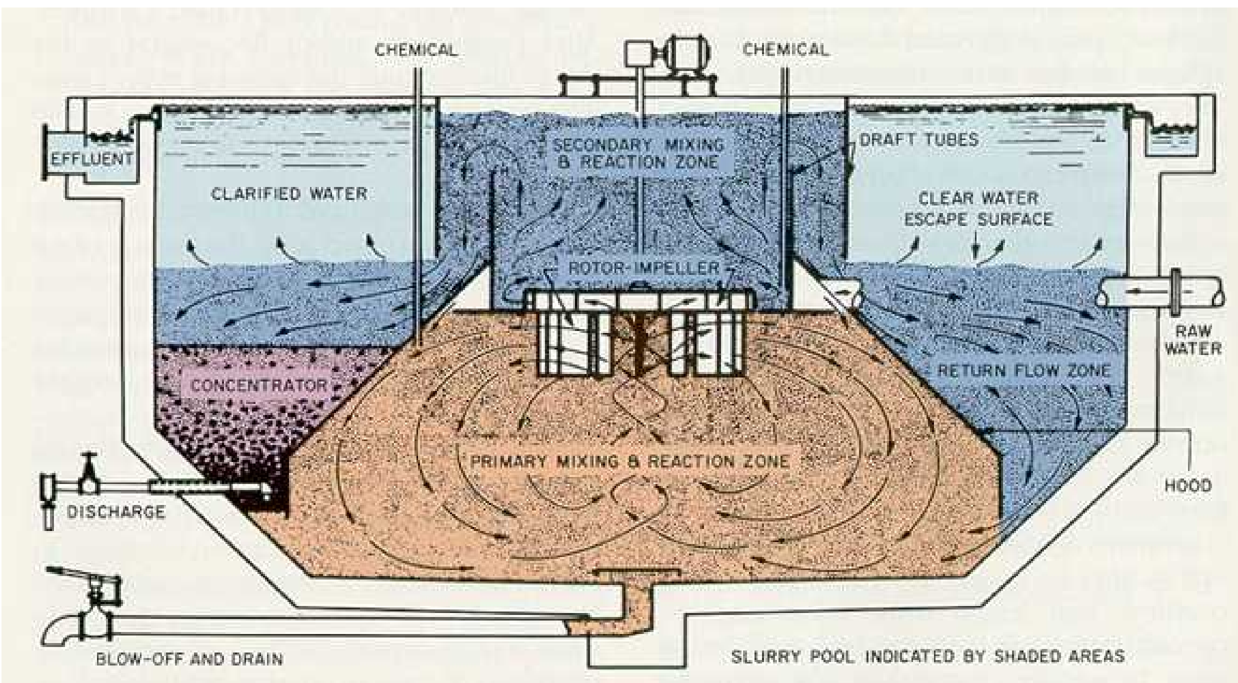


Figure 9: Zones in a typical solids contact clarifier.

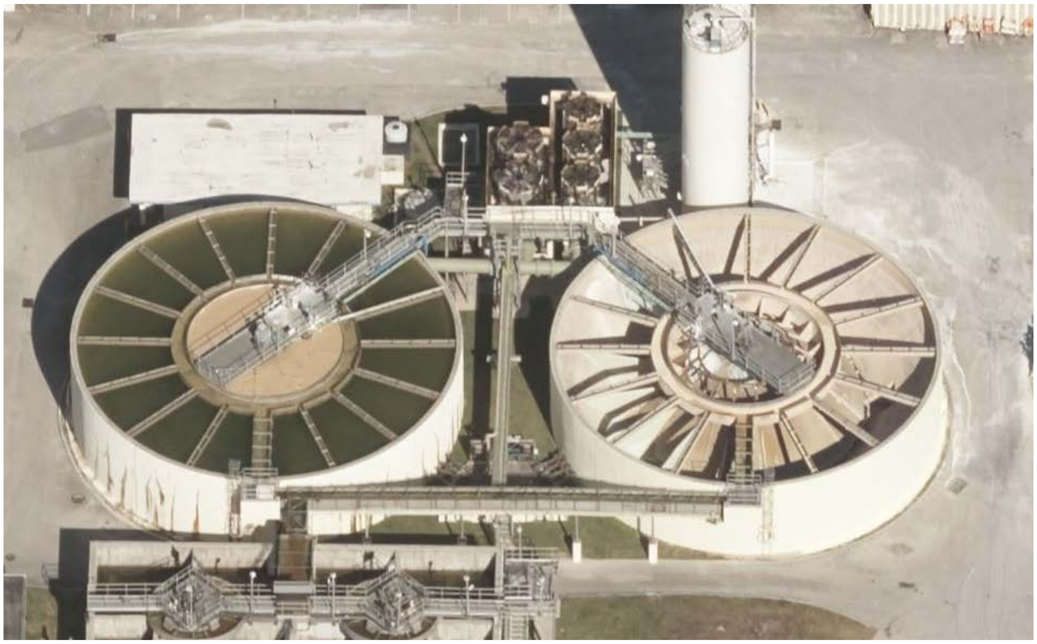


Figure 10: Example of two solids contact clarifiers for lime softening of water. Raw water is pumped into aerators (in the center) and then flows by gravity to the two clarifiers. Effluent flows by gravity to sand filters. The lime silos can be seen behind the empty clarifier.

Steps in Clarifier Rehabilitation

There are several important steps in the rehabilitation process, regardless of the type of clarifiers involved. These steps are presented in Figure 11 and explained in subsequent sections. The first four steps may be considered part of the study or preliminary design phase of the project.

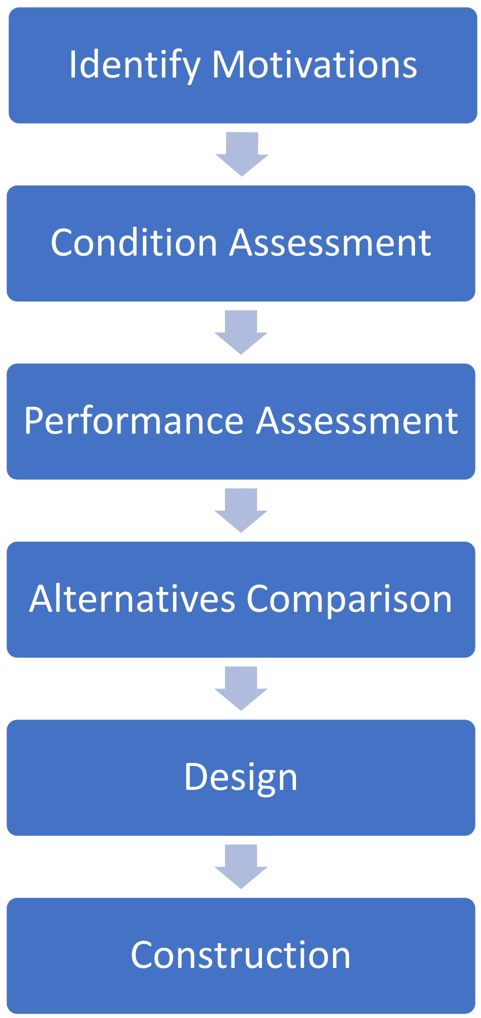


Figure 11: Steps in the Clarifier Rehabilitation Process

Identify Motivations

As an engineer, it is important to know the motivating factors behind any new project, and this is no different for a clarifier rehabilitation project. If the reasons for needing rehabilitation are forgotten, there is an increased likelihood of not fixing the problems. A key to a successful project is to identify the motivating factors and keep them front and center through the end of the project.

The following table presents common motivating factors and the resulting focus for the rehabilitation design.

Table 1: Potential Motivations for a Clarifier Rehabilitation Project and Resulting Focus for Preliminary Design

Motivating Factor	Condition Assessment	Performance Assessment	Alternatives Comparison
Coating Failure	**Critical**	Optional	Optional
Equipment Failure	**Critical**	Optional	Optional
End of Equipment Life Span	**Critical**	Optional	Optional
Process Problems	Optional	**Critical**	**Critical**
Performance Improvement Desired	Optional	**Critical**	**Critical**
Flow Demand Increase	Optional	Optional	**Critical**

Condition Assessment

All physical components of the clarifier should be reviewed and an opinion of the condition provided. Results should be compiled in a report and used for making design decisions. Before getting your hands dirty onsite, the following information should be gathered, if available:

- Record Drawings (aka As-Built Drawings)
- Manufacturer's Shop Drawings and O&M Manuals
- Previous Assessments or Reports, if available
- Historic Pictures, if available

Be sure to confer with others throughout the condition assessment process. The following are potential experts for collaboration:

- Clarifier manufacturers and representatives
- Consultant with experience in clarifier rehabilitation
- AGMA consultant member (for the gear drive)
- Structural engineer (for the equipment and tank)

Clarifier components can be grouped into the following categories, each of which is discussed in detail in this section:

- Drive
- Mechanical Equipment
- Tank (Concrete or Steel)
- Support Features

Drive

The drive unit is the heart of the clarifier. When it fails, the whole clarifier will be offline until the drive is repaired or replaced. So it is of prime importance to have confidence in the condition of the drive. The main types of drives are as follows:

- Bridge supported - typical of small wastewater clarifiers
- Center pier supported - typical of large wastewater clarifiers
- Compression ring supported - some solids contact clarifiers

Figures 12 and 13 show example clarifier drives.


Figure 12: Compression ring supported drive for a solids contact clarifier (left) and a bridge supported drive for a secondary clarifier (right).

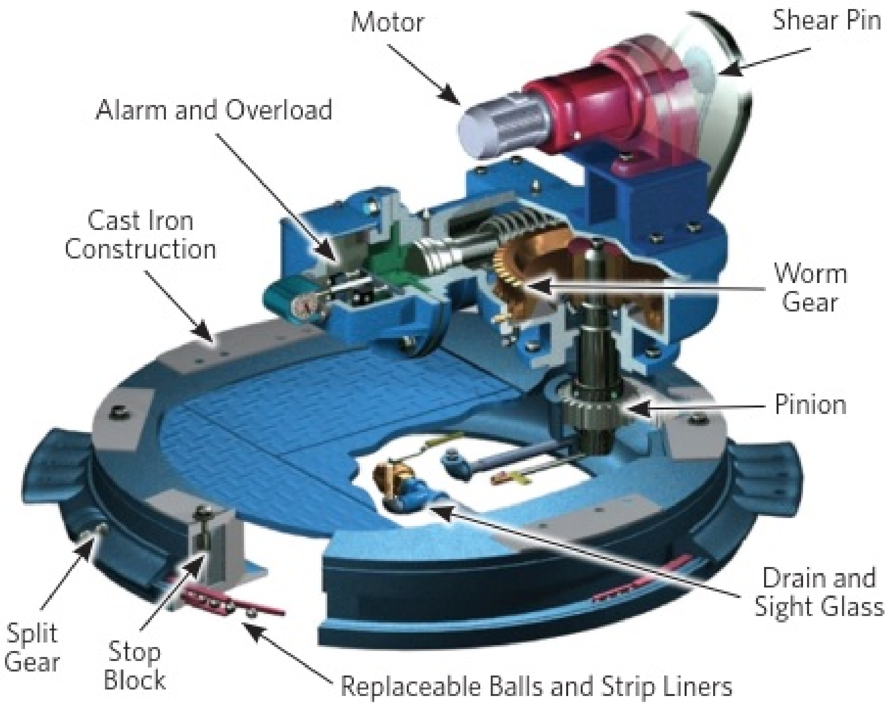


Figure 13: Center pier supported drive with major components identified
Source: Evoqua Water Technologies

Electric motors are typically less than 1 HP on wastewater clarifiers. Solids contact clarifiers have larger drives, often from 10 to 30 HP, since considerable mixing energy is required. Some solids contact clarifiers have two separate drives: one for rotating the sludge collection mechanism and one for rotating the rotor impeller.

When an engineer assesses the condition of the drive, an attitude of humility is helpful. It is unlikely that an engineer can look and listen to a drive and make a conclusion on the condition. Most drive failures occur over weeks or months, and problems reveal themselves slowly and only under certain conditions. Operations and maintenance staff have spent valuable time caring for the drive. Ask them about past work on the drive. Discuss recent drive problems. And ask for their insights on how the drives can be rehabilitated.

If there has been a history of significant problems with the drive or if it is at the end of its useful life, replacement of the drive may be recommended without further assessment. Which begs the question:

> *What is the life of a clarifier drive?*
>
> Short Answer: Typically 20 years
>
> Long Answer: Drive components are designed for a number of cycles at a rated load and with a service factor. For example, bearings are typically designed for a minimum L-10 life of 400,000 hours, or 45 years of continuous operation. However, based on actual operating conditions, drive maintenance typically becomes excessive after 20 years of operation. Many clarifier drives have lasted more than 30 years without significant rehabilitation, and more than 40 years with rehabilitation.

It is important that a spare drive unit is available onsite. The history and condition of the spare drive should be assessed. Confirm that the stored drive has been rotated regularly. Consult the Operation and Maintenance Manual (O&M Manual) for any additional maintenance required during storage.

A number of field tests can be done to evaluate the condition of the drives in service. Common tests are summarized in Table 2.

Table 2: Field Tests for Troubleshooting a Clarifier Drive			
Test	Instrument	Guidelines	Typical Limit
Vibration	Accelerometer	Mount on the drive base and measure the filtered vibration spectra versus frequency and the vibration phase in three perpendicular planes	3.0 mils peak to peak displacement
Noise	Sound Level Meter	Hold 3 feet from the drive and measure for each of the 8-octave band mid-points. Repeat on each side of the drive.	85 dBA
Amp Draw	Varies	Read the amperage draw of the motor during operation, and compare with design value. An electrician may be required.	Project Specific
Speed Change	N/A	If possible, vary the speed of the drive to the low and high range, and repeat the above tests.	N/A

If multiple drives are being assessed, it is important to compare the results between the different drives. Check if one drive has a significantly higher vibration, noise, or amp draw. That is a sign that the gear drive is having a problem.

Mechanical Equipment

Each clarifier has a unique set of equipment. This makes assessing the condition both interesting and challenging. The condition assessment is of high priority if the clarifier equipment has experienced coating failure, a corrosion problem, a mechanical failure, or a structural failure.

The recommended steps for the condition assessment are shown in Figure 14 and described as follows.

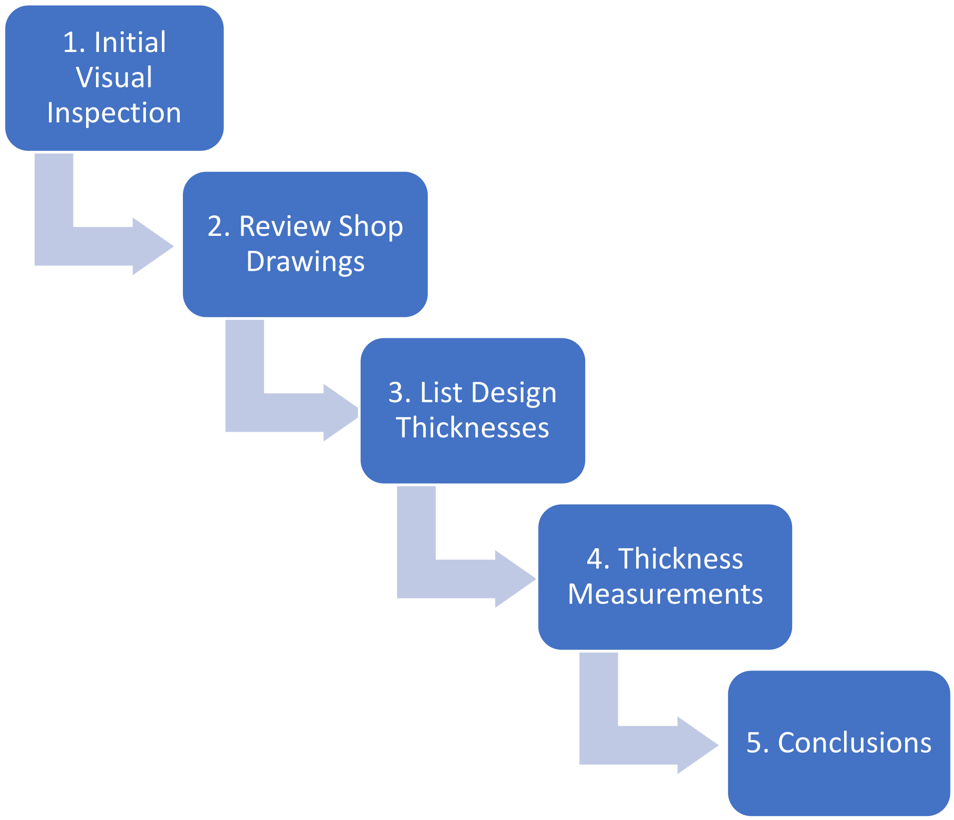


Figure 14: Steps in the Assessment of Clarifier Mechanical Equipment

Step 1 – Initial Visual Inspection:

- Get familiar with the equipment onsite. Gain an understanding of how each component functions.
- Take photographs of onsite equipment.
- Visually inspect the condition of welds, fasteners, squeegees, pipes, etc.
- Record obvious problems such as coating failures, corrosion, holes, missing bolts, worn items, bent members, warped plates, etc. See Figure 15 for an example.

Figure 15: Solids contact clarifier with holes in the hood plates (top) and significant corrosion on the compression ring angles (bottom). These problems cannot be seen from the walkway, highlighting the need for an interior inspection.

Step 2 – Review Shop Drawings:

- Confirm the equipment matches the original shop drawings. Note any differences and inquire as to when and why changes were made. Request the shop drawings from the manufacturer if they cannot be located.
- Confirm which members are carbon steel and which are other materials.
- Check the original coating type and thickness.
- Find the member thicknesses for all plates and members such as angles, channels, and beams.
- Check for a note regarding minimum steel thickness. Often submerged steel is designed with a minimum thickness of 1/4” to account for potential corrosion or wear on thin steel components.
- Check for a note regarding “corrosion allowance”. Typically submerged steel is designed with a corrosion allowance of 1/16”. Sometimes 1/8” is used for additional conservatism. For example, with 1/16” corrosion allowance specified, if a member must be 1/4" thick per structural calculations, the member will be sized as a minimum of 5/16” thick (1/4” plus 1/16”) with the corrosion allowance.

Step 3 – List Design Thicknesses:

- Make a list of the steel plates and members with the design thickness (from Step 2). This will be used to compare with measurements in Step 4.

Step 4 – Thickness Measurements:

- Take thickness measurements for all steel plates and members. This can be done with an ultrasonic thickness gauge, as shown in Figure 16. Record these readings on the list from Step 3.
- Take coating thickness measurements with a coating thickness gauge, as shown in Figure 17, if consideration is being given to keeping some of the existing coating system. Typically all steel members are recoated as part of the rehabilitation work, so this task is not always required.

Figure 16: Steel thickness measurement with an ultrasonic thickness gauge.
In this example, the design thickness was 1/4" with a 1/16" corrosion allowance, so the minimum thickness is 3/16", or 0.19". This gauge is reading 5.9 mm, or 0.23", which is above the minimum and therefore acceptable. Note the conversion: 1 inch = 25.4 mm.

Figure 17: Coating thickness measurements with a coating thickness gauge that reads in mils dry film thickness (DFT). One mil is one-thousandth of an inch thick. Submerged carbon steel is often coated a minimum of 12 mils DFT.

Step 5 – Conclusions:

- Compare the actual thickness measurements to the design thickness values. List the components with a loss of steel greater than the corrosion allowance (1/16" if unknown).
- Review results with a structural engineer and decide which steel members are deficient. Main structural supports should be given special consideration.
- For each major component, recommend either spot repairs, significant repairs, or complete replacement.
- Document condition assessment findings and conclusions.

Steel Tank

It is common for small clarifiers to be constructed with steel tanks, especially solids contact clarifiers. Steel tanks can last as long as concrete tanks, however, they require maintenance to maintain the coating system. The steel tank should be inspected with the same steps described above for the mechanical equipment. If the floor is concrete, advice for concrete inspection is provided in the subsection entitled *Concrete Tank*.

As an example, project engineer Todd was tasked with assessing the condition of a steel tank for a solids contact clarifier at the local water treatment plant. He reviewed the shop drawings which show the tank is made of 1/2" thick carbon steel with L3x3x3/8 stiffener angles. A corrosion allowance of 1/16" is assumed, so the tank wall should have a minimum thickness of 7/16", or 0.44".

Todd inspected the inside and outside of the tank and found the following deficiencies:

- Along the top of the tank, the steel wall has several depressions and holes, as shown in Figure 18.
- At the base of the tank, the steel wall has three depressions, as shown in Figure 19. Todd measured the steel thickness in the depressions with the following results: 0.304", 0.360", and 0.428". These results are all less than the minimum thickness of 0.44".

After reviewing these with the structural engineer, it was decided that additional steel reinforcing was needed to restore the integrity of the tank at these locations.

Figure 18: Depressions and holes near the top of the tank wall.

Figure 19: Bottom of a tank wall with the three depressions circled and steel thickness measurements written in green.

Concrete Tank

Assessing the condition of a concrete tank is significantly different than the rest of the clarifier. The recommended steps for the condition assessment are shown in Figure 20 and described as follows.

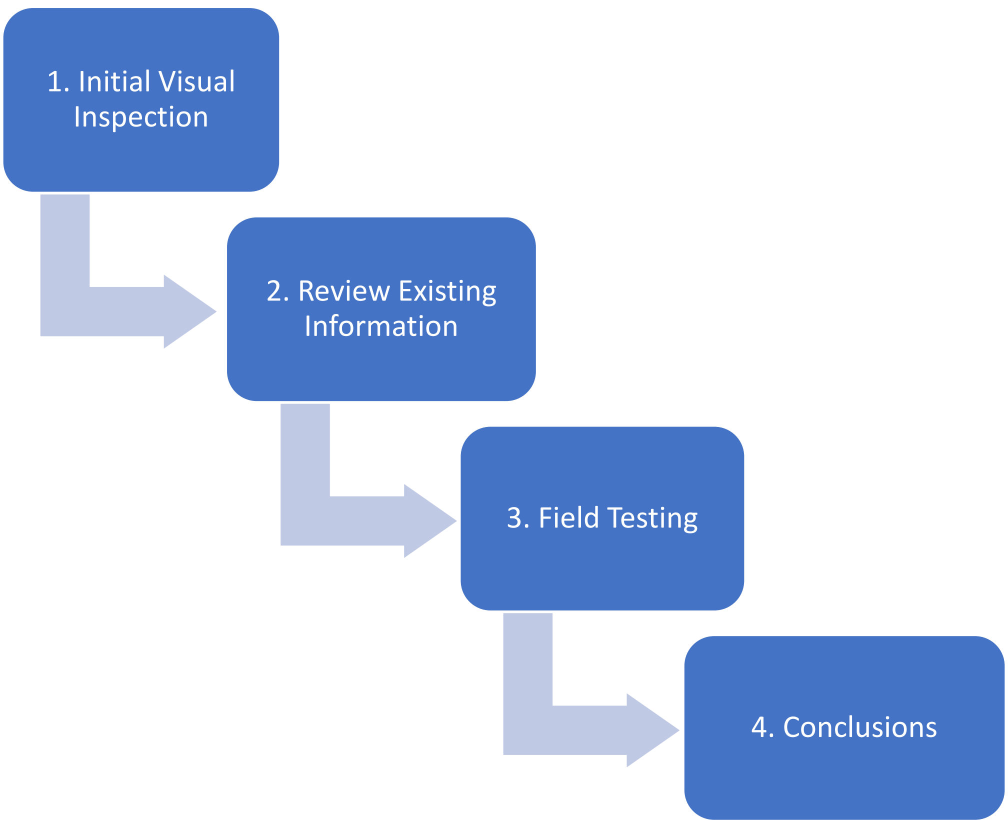


Figure 20: Steps in the Assessment of a Concrete Tank

Step 1 – Initial Visual Inspection:

- Get familiar with the tank and its features.
- Take photographs of inside and outside of the tank.
- Visually inspect the condition of the concrete.
- Record locations of any leaks, efflorescence buildup, cracks, chips, discoloration, or uneven settling. See Figure 21 for an example.

Figure 21: Example of efflorescence on the outside of a tank wall. Efflorescence is from soluble salts in the concrete being brought to the surface from passing water, thus indicating there is a slow leak in the area.

Step 2 – Review Existing Information

- Confirm the tank matches the original drawings. Note any differences and inquire as to when and why changes were made.
- Review the foundation, floor, the wall (prestressed, precast, or cast-in-place), and dome/roof type (if any).
- Check the original coating type and thickness. Inquire when the tank was last coated.
- Inquire as to when any leaks started and if repairs were previously performed. Find any previous inspection reports or repair documentation.

Step 3 – Field Testing

- Based on the visual inspection results and the existing information, decide on the field testing to further investigate the condition of the concrete tank.
- The following are common field tests for concrete tanks. Testing should be carried out under the direction of an experienced inspector.

- Non-destructive tests:
  - Rebound hammer test to discover voids in the concrete or areas of low strength near the surface. See Figure 22.
  - Ultrasonic pulse velocity or pulse-echo (UPE) test to check the strength, quality, and thickness of concrete.
  - Ground-penetrating radar (GPR) test to review the locations of steel reinforcing and delaminated concrete.
  - Cover meter test to check the cover for steel reinforcement.
  - Surface Electrical Resistivity test to check the durability of the concrete.
  - Half-cell Corrosion Mapping test to identify areas of active corrosion. Coatings need to be removed for this test.

Figure 22: An example of a test hammer instrument that gives an estimated strength reading in psi (MPa).

- Destructive tests:
  - Surface removal test involves cutting or chipping the surface of the concrete to view the condition of the steel reinforcement. This test can be done in several different locations to gain a direct view of the condition of the tank. See Figure 23 for an example.
  - Core test by removing a cylinder of concrete to test the compressive strength and other properties. Care must be taken to properly restore the concrete in the area of the core.

Figure 23: Surface removal panel on the outside wall of a 40-year-old prestressed concrete tank. The wires are observed to be in good condition.

Step 4 – Conclusions:

- Review inspection results with a structural engineer and decide the severity of the deficiencies discovered.
- Document condition assessment findings and conclusions.

Support Features

A clarifier requires many support features to function properly. Some examples include:

- Chemical feed system
- Scum pumping system
- Sludge pumping system
- Sludge blow-off valves with actuators
- Piping and valves for influent, effluent/supernatant, sludge, scum, spray water, chemical feed, sampling, etc.
- Dome cover
- Odor control features
- Control panels (see Figure 24)
- HMI screens and controls programming
- Electrical wiring, breakers, disconnects, VFDs, etc. (see Figure 25)
- Instrumentation, including sludge blanket detectors, samplers, solids meters, flow meters, level sensors, limit switches, and pressure transmitters.

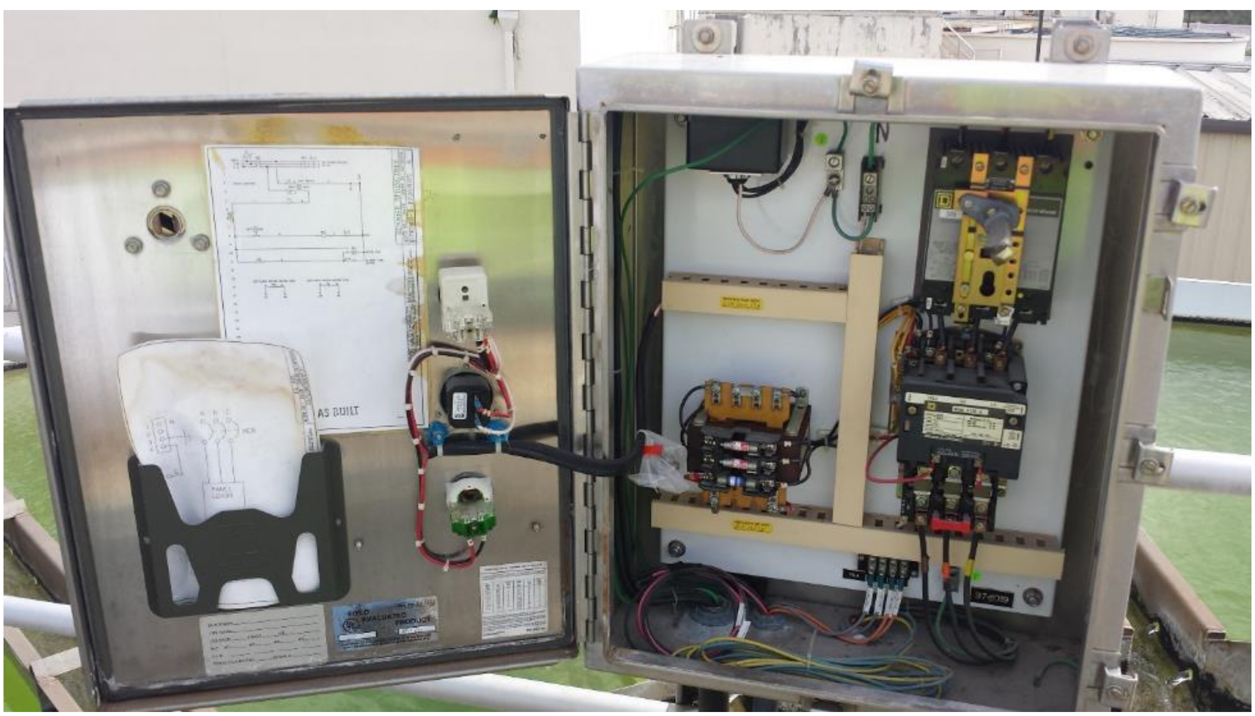


Figure 24: A 15-year-old control panel on a clarifier.

Figure 25: A 30-year-old disconnect switch on a clarifier.

These ancillary items should be assessed along with the main components of the clarifier. There is little sense in spending hundreds of thousands of dollars to rehabilitate a clarifier only to have it fail because of an old valve or a deteriorated electrical part. As an engineer, you should consider all potential failures of the clarifier, and thus assess the condition of these support features as well. An electrical engineer or electrician should assist in the evaluation of electrical and controls components.

Performance Assessment

The purpose of a clarifier is for treating water or wastewater. So ultimately, no matter how great the condition the components, if the clarifier is not treating the water or wastewater properly then changes are needed. The performance assessment step aims to evaluate the efficiency of the treatment and identify modifications that can improve the treatment.

This section reviews common procedures for assessing the performance of a clarifier. However, since each clarifier is unique, each performance assessment will also be unique. An engineer should consider what is appropriate for the application and consult with process experts.

Common steps in a performance assessment are as follows:

1. Gather Information
2. Desktop Study
3. CFD Modeling (Optional)
4. Field Testing (Optional)
5. Recommendations

Step 1 – Gather Information:

- Review the process flow diagram for the treatment plant and modify it based on current operations. Walk the plant to confirm all relevant processes have been incorporated.
- Gather historic information including the following:
    - Flow rates through the clarifier
    - Sludge withdraw rates
    - Return Activated Sludge (RAS) rate (for secondary clarifiers)
    - Solids concentrations of influent, effluent, and sludge
    - Sludge blanket observations
    - Chemical feed rates and concentrations
    - Water quality parameters (pH, alkalinity, solids, etc)
- Review any previous design reports or process studies.

Step 2 – Desktop Study

- Perform a mass balance for the clarifier. This will provide insight into how flow and solids pass through the clarifier. See Figure 26 for an example.

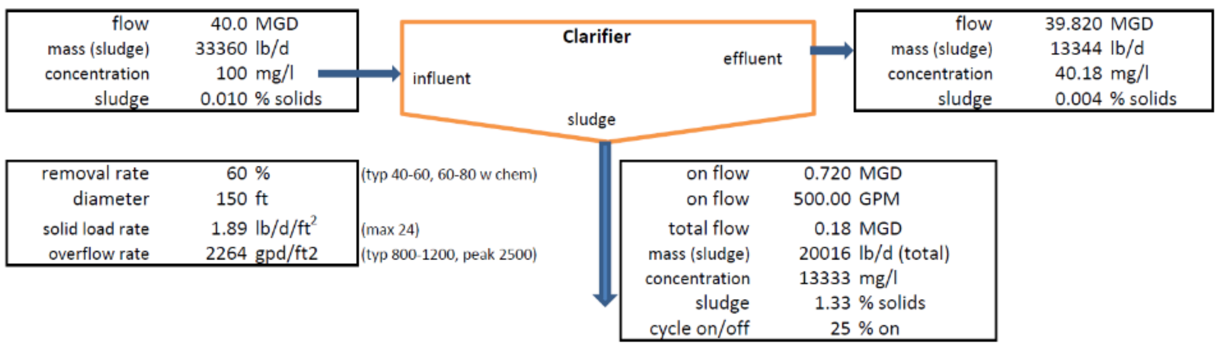


Figure 26: Example mass balance for a primary clarifier at peak flow. Note the mass of sludge entering the clarifier (33,360 lb/d) equals the mass leaving the clarifier (13,344 lb/d in effluent plus 20,016 lb/d in sludge).

- Calculate important operating parameters at average and peak flow conditions. Typical parameters and formulas are as follows:
  - Surface overflow rate = influent flow rate / surface area
  - Detention time = tank volume / influent flow rate
  - Solids loading rate = solids rate / surface area
  - Weir overflow rate = effluent flow / length of weir)
  - Solids removal rate = 1 – effluent solids conc. / influent solids conc.
    - Similar for BOD, turbidity, and phosphorus removal rates
  - Side water depth = water surface elevation - base of tank wall elevation
  - Chemical dosage (mg/L) = feed rate (lb/d) / (flow rate (MGD) x 8.34)
  - Final drive speed and/or mixer speed
  - pH of influent and effluent (for lime softening)
- Compare the calculated parameters to industry standards and review with clarifier process experts to identify potential concerns and potential process modifications that could improve performance.
- For secondary clarifiers and gravity thickeners, state point analysis may be used to understand the operating condition and determine corrective actions such as changing the RAS rate, the influent solids concentration, or the influent flow rate. Settling testing is required (as summarized in Table 3) to produce a settling flux curve. Then the overflow and underflow rates are used to determine the current operating point, or "state point". See Figure 27 for an example state point analysis chart.

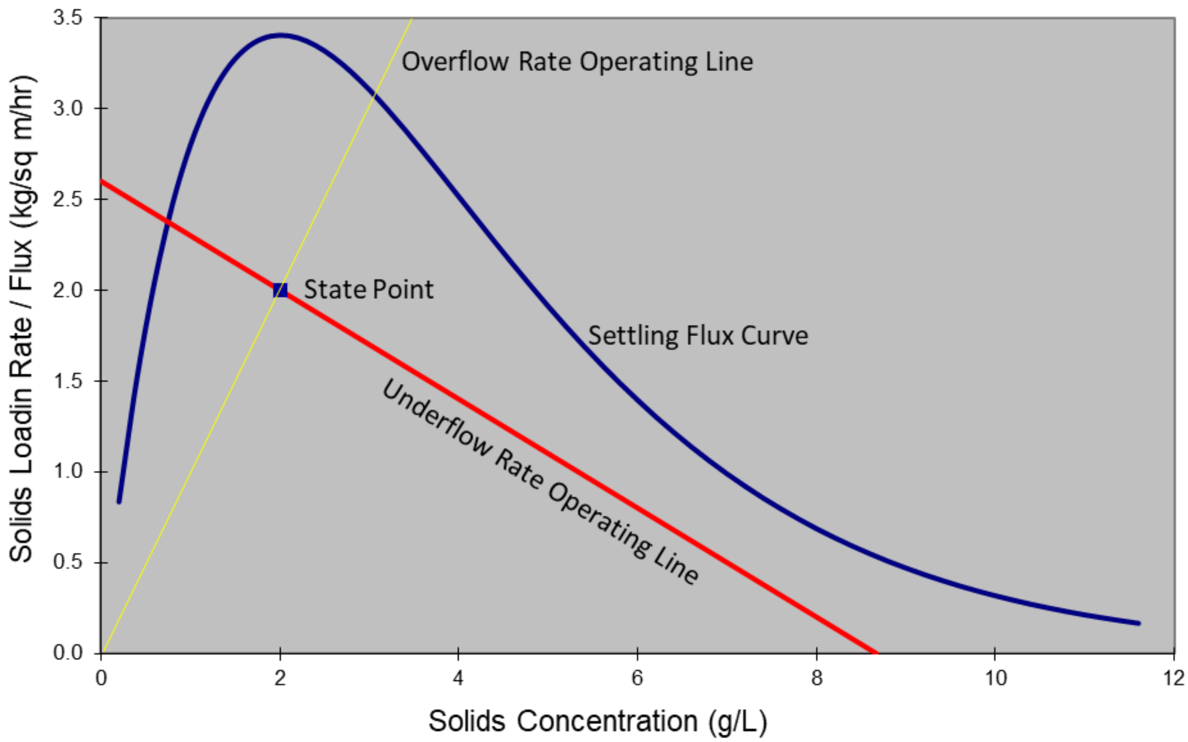


Figure 27: State point analysis chart with labels for the three plotted lines.

Step 3 – CFD Modeling

- Computational fluid dynamics (CFD) has been successfully applied to clarifiers for decades. Recent advances in computing power and CFD software have made this technique increasingly popular, especially for large wastewater clarifiers. However, it is still relatively expensive, with a starting cost of around $20,000.
- CFD modeling provides helpful insights into the clarifier performance and can help determine the following:
    - Peak flow rate and solids loading rate capacities
    - Improvements to the inlet arrangement to minimize velocity vectors
    - Improvements at the effluent such as current density baffles
- See Figure 28 for an example.

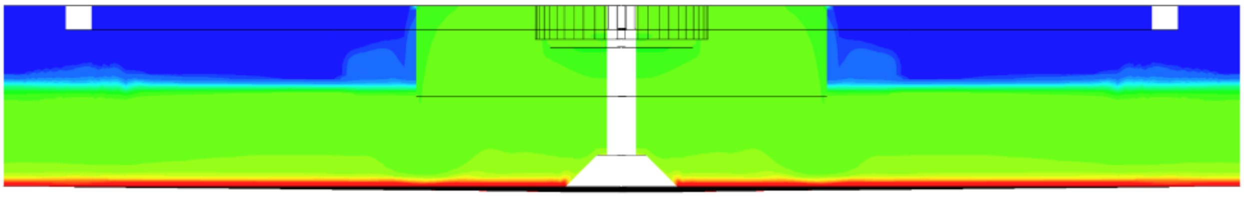


Figure 28: CFD model results for solids concentration of a secondary clarifier. Colors are as follows: dark blue is 10 mg/L, light blue is 1,000 mg/L, green is 3,000 mg/L, and red is 6,000 mg/L.

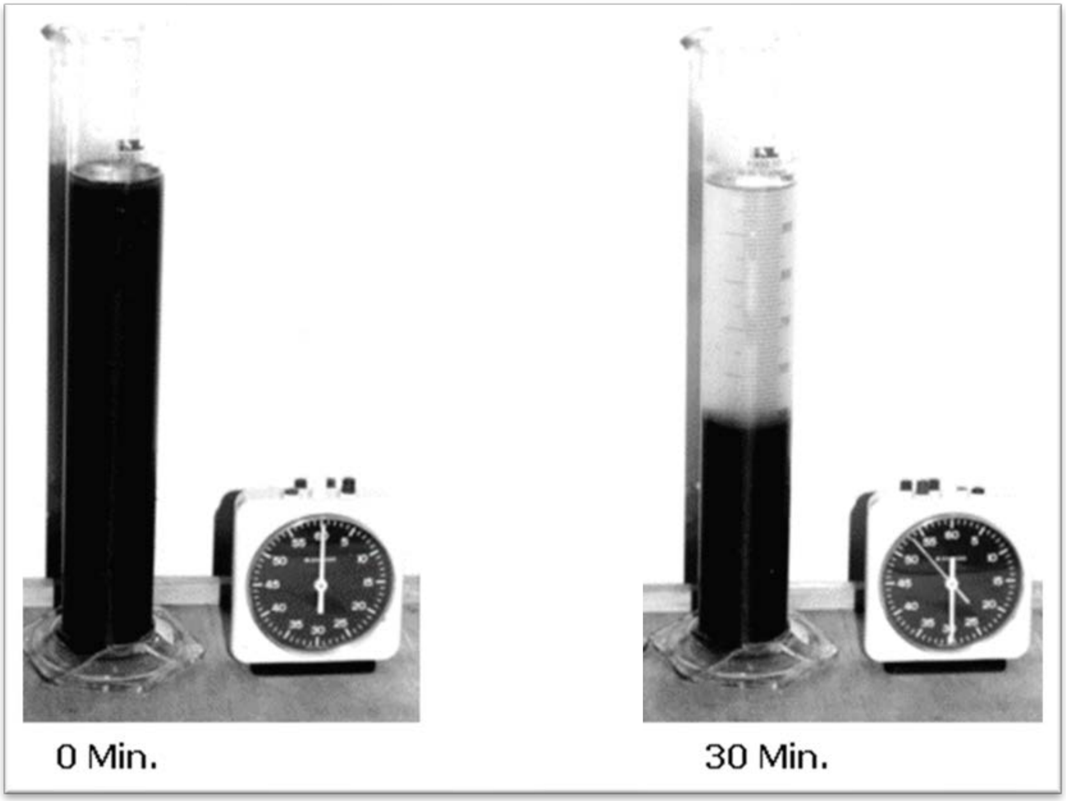
Step 4 – Field Testing

- Field testing can identify weaknesses in a clarifier and help discover how to optimize clarifier performance.
- To help decide which tests should be undertaken, consider the original motivation for the clarifier rehabilitation project. Also consider any parameters that are outside the industry standards, as identified in the desktop study. Choose tests that have the greatest chance of helping resolve the problems. As always, gain input from clarifier experts.
- For wastewater clarifiers, potential field tests to consider are summarized in Table 3.
- For lime softening clarifiers, consult with the equipment manufacturer for specific tests to consider. The following are potential process modifications to consider:
    - pH adjustment, typically with a Carbon Dioxide (CO2) Feed System
    - Lime feed rate changes
    - Polymer feed rate changes
    - Sludge withdrawal frequency
    - Mixer speed changes
    - Mixer blade clearance modifications
    - Influent flow rate equalization
    - Upstream aeration

Step 5 - Conclusions

- Review performance assessment results with clarifier experts and compile a list of potential process modifications.
- Document performance assessment findings and conclusions.

Table 3: Field Tests for Wastewater Clarifier Performance Assessment			
Test	Instrument	Overview	Type of Clarifier
Tracer Test	Fluorescent Dye and Spectro-fluorometer	Dye is introduced just upstream of the clarifier and samples are obtained from the effluent at time intervals. Create a flow curve by plotted concentration over time. Samples can be taken at vertical intervals to view flow patterns within the clarifier.	All
Current Test	Drogue (X-vaned flow catcher)	Lower the drogue into the clarifier at different depths with a float. Track the movement over time of the float to identify strong currents within the clarifier.	All
Microscope Viewing	Microscope	Exam biological floc in a microscope to determine types and abundance of biota. If filaments are observed, consider process modifications.	Secondary
Settling Test	Settleometer or Graduated Cylinder	Measure settle sludge volume over 30 minutes, as shown in Figure 29. Measure solids in the supernatant. Mix before the test and repeat to understand the impact of flocculation. Calculate the sludge volume index (SVI) and compare it to industry standards. Create a flux curve and state point analysis chart.	Secondary
Sludge Blanket Level	Core Sampler	Lower core sampler to the floor and close bottom valve. Raise to view sludge depth. Repeat at intervals along the clarifier radius.	All
Vertical Solids Profile	Suspended Solids Analyzer	Use core sampler to take sludge samples at vertical intervals (6" or 12") and test for suspended solids. Make a vertical plot such as Figure 30.	Gravity Thickener
Chemical Jar Testing	Gang Stirrer and Turbidimeter	Place influent samples in multiple containers with different chemical concentrations. Flocculate and measure settle solids volume and effluent solids concentration or turbidity after 30 minutes. See Figure 31.	Chemical Enhanced



$$\text{SVI (mL/g)} = \frac{\text{Settled Sludge Volume (mL/L)}}{\text{Mixed Liquor Suspended Solids (g/L)}} \times 1{,}000$$

Figure 29: Settling test showing the original sludge volume (left) and settled sludge volume after 30 minutes (right). The SVI formula is included for convenience.

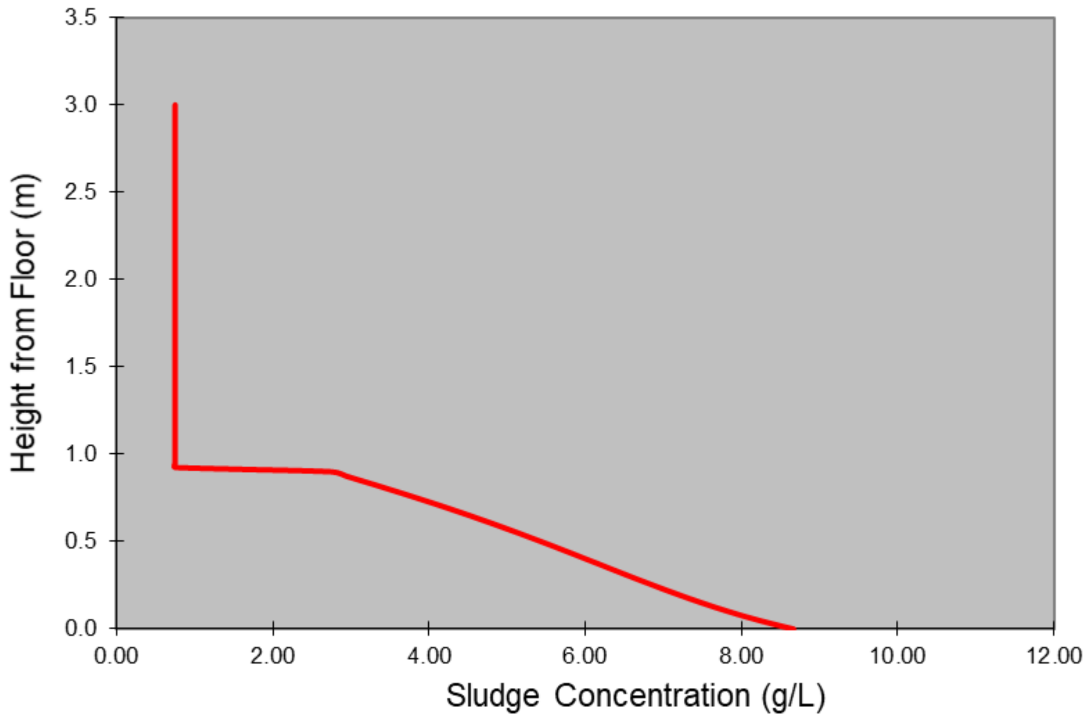


Figure 30: Example vertical solids profile for a gravity thickener.

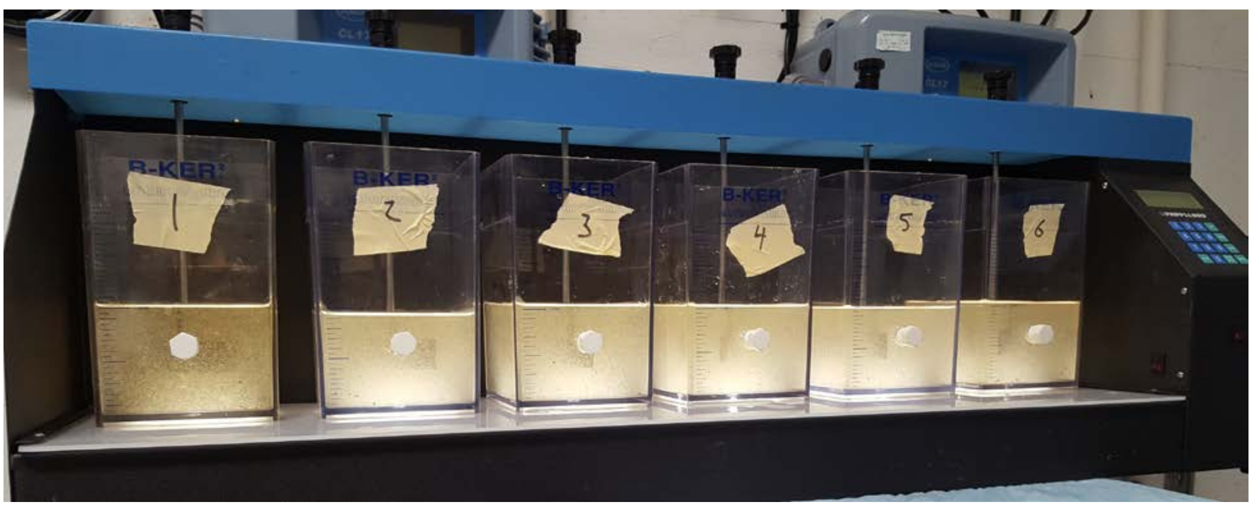


Figure 31: Jar testing with a gang stirrer and six influent samples, each with different chemical dosages. After 30 minutes, supernatant turbidity was measured for each.

Alternatives Comparison

The conclusions from the condition and performance assessments should be used to identify and develop several alternatives that will address the deficiencies. The following steps can be used to compare the alternatives:

1. Identify Design Criteria
2. Brainstorm List of Alternatives
3. Qualitative Comparison of Alternatives
4. Quantitative Comparison of Alternatives
5. Final Selection

Step 1 – Identify Design Criteria

- Select design criteria that represent the Owner's needs and values, and that address the original motivation for the clarifier rehabilitation project.
- Ideally, select four to six independent criteria.
- Consider selecting at least one criterion from each of the three categories of sustainability. The following are example criteria:

    1. Economic Criteria:
        a. Capital Cost
        b. Construction Cost
        c. Operating Cost
        d. Lifecycle Cost
        e. Litigation Risk
        f. Life Span

    2. Environmental Criteria:
        a. Potable Water Consumption
        b. Stormwater Management
        c. Solid Waste Produced
        d. Energy Consumption (nonrenewable)
        e. Recycling / Beneficial Reuse
        f. Greenhouse Gas Emissions (non-biogenic)
        g. Air Pollution
        h. Water Pollution

3. Social Criteria:
    a. Employee Productivity
    b. Safety
    c. Chemical Use
    d. Regulatory Acceptance
    e. Aesthetics
    f. Land Use / Footprint

Step 2 – Brainstorm List of Alternatives

- Become familiar with recent advances in clarifier technology. Reach out to equipment suppliers to review the latest technologies. Review recent case studies in technical journals or at conferences.
- Create a list of potential improvements and group them into unique alternatives.

Step 3 – Qualitative Comparison of Alternatives

- Create a qualitative comparison table of alternatives with the selected criteria and list of alternatives. See Table 4 for an example.
- And the qualitative terms to compare each alternative for each criterion, such as "Best, Average, Worst" or "Good, Fair, and Poor".

Table 4: Example Qualitative Comparison of Initial Alternatives

Alt.	Description	Constr. Cost	Lifecycle Cost	Energy Use	Land Use	Reliability
A	Retrofit and No Process Change	**Best**	**Best**	**Best**	**Best**	Worst
B	Add Chemical Enhanced Clarification	Average	Average	Average	Average	Average
C	Retrofit and Add a Clarifier	Average	Average	Average	Worst	**Best**
D	Convert to High-Rate Treatment	Average	Average	Average	Average	Average
E	Convert to MBR	Worst	Worst	Worst	Average	**Best**

Step 4 – Quantitative Comparison of Alternatives

- Select two or three of the best alternatives from the qualitative comparison. Define the overall scope of work for each alternative.
- Calculate the approximate criteria values for each alternative. For example, estimate the construction cost to one or two digits.
- Create a quantitative comparison table of alternatives with the selected alternatives and actual calculated values. See Table 5 for an example.
- A multi-criteria scoring table can also be created to provide a final score for each alternative. This approach uses weight factors to account for some criteria being more important than others. See the Helpful References section for more information.

Table 5: Example Quantitative Comparison of Selected Alternatives

Alt.	Description	Constr. Cost	Lifecycle Cost	Energy Use (kWh/yr)	Land Use (ft^2)	Reliability
1	Retrofit Equipment – No Process Change	$1M	$2M	6,500	0	No redundancy at peak flow
2	Retrofit and Add a Clarifier	$3M	$4M	10,000	40,000	Full redundancy
3	Convert to MBR	$8M	$12M	300,000	10,000	Full redundancy

Step 5 – Final Selection

- Review each alternative and the comparison table with the Owner and other stakeholders.
- Select a single alternative for design.

Design

The design phase is when engineers typically feel the most comfortable. A typical design-bid-build project includes the following deliverables:

- Design Report
- Drawings
- Specifications
- Cost Estimate
- Permit Approvals

Design Report

The contents of the design report will depend on if the primary purpose is for a permit submittal or for the client. For permit submittals, the design report is typically shorter and may not include details of the condition assessment, performance assessment, and alternatives analysis. A potential format for the report is as follows:

1. Background
2. Purpose
3. Permit Requirements
4. Clarifier Rehabilitation
    a. Process/Mechanical
    b. Structural
    c. Electrical
    d. Instrumentation and Controls
5. Other Improvements
6. Implementation Schedule
7. Cost Estimate
8. Appendices

Address Potential Differing Conditions

For a rehabilitation or retrofit project, the design engineer should keep in mind that the Contractor is likely to encounter differing conditions and may claim additional time and cost. The design engineer should strive to minimize these events to the extent possible by incorporating the following into the drawings or specifications, as appropriate for the project:

- Contractor shall fully clean the inside of the clarifier including pressure washing submerged equipment and removing any solids buildup on the floor.

- Identify any areas of the clarifier that were not fully inspected. Consider potential problems that may be encountered in those areas during construction.
- For areas with unknown conditions, specify for the Contractor to perform tests, such as taking steel thickness measurements, and submit the results for the Engineer to review. Thickness measurements should be taken after blasting, as additional areas of thin steel often reveal themselves at that time, as seen in Figure 32.
- Consider specifying an allowance or an assumed amount of unspecified repairs. For example, the bid shall include 2,000 pounds of unspecified steel plate reinforcing in locations determined in the field by the Engineer/Consultant.
- Unit pricing for additional repairs can be requested with the bid.
- Create separate plan and profile drawings showing the existing clarifier conditions. The drawings showing the improvements should have the existing clarifier in light lines and the improvements in dark lines for clarity.
- Include an abundance of photos of the internal components of the existing clarifier to help define existing conditions.

Figure 32: Example of thin steel discovered during construction after sandblasting.

Summary Table

In the specifications, it is helpful for all parties to have a clarifier rehabilitation table that identifies the work on the clarifier components for each clarifier. This is especially helpful if there are multiple clarifiers with different work being performed on each clarifier. See Figure 33 for an example of a summary of work table.

Component	Provide for Clarifier				Notes
	East		West		
	No. 5	No. 6	No. 7	No. 8	
Rotor Drive	X	X	X	X	Replace existing.
Control Panel for Rotor Drive	X	X	X	X	Replace existing.
Rotor Impeller	X	X			Replace existing.
Launders and Outer Draft Tube	X	X			Replace fiberglass launders with 316L.
Concentrator gates, hinges, brackets, rods, handle, etc	X	X	X	X	Quantity four sets per clarifier.
Compression Rings	X	X			Replace existing.
Access Hatches in Skirt and Hood	X	X	X	X	Replace carbon steel with fiberglass.
Valve and pipe replacements	X	X	X	X	See Drawings.
24” Influent Pipe modifications	X	X	X	X	Add Air Separation Chambers. See Drawings.
Patching tank walls and platform support	X	X			See Drawings.

Figure 33: Example clarifier rehabilitation summary table.
An “X” indicates replacement of the component.

<u>Define the Details</u>

Make details with clear notes for special repairs. Typically seal welding is required for submerged connections to avoid water entering between plates and causing corrosion. This should be specified with a weld symbol or a note. See Figure 34 for an example.

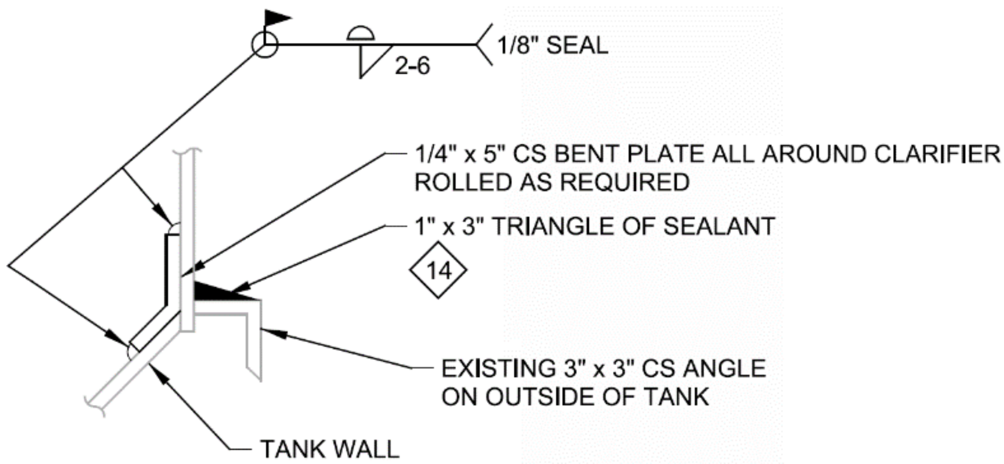


Figure 34: Example detail for adding a reinforcing plate and sealant to a tank tall.

Materials and Coatings

To avoid the need for recoating all carbon steel components, alternate materials and coatings can be considered, as summarized in Table 6.

Table 6: Material and Coating Options for Submerged Clarifier Components

Material	2020 Raw Cost ($/lb)	Coating	Estimated Prevalence	Expected Recoat Time	Estimated Life Span
Duplex Stainless Steel	$3.00	None	1%	None	50 years
316L Stainless Steel	$2.20	None	4%	None	40 years
304L Stainless Steel	$1.60	None	5%	None	30 to 40 years
Carbon Steel	$0.40	Coated, Properly Applied	60%	15 years	30 to 40 years
		Galvanized	20%	15 years	30 to 40 years
		Coated, Improperly Applied	20%	5 to 10 years	20 to 30 years

Ideally, all submerged metal should be of the same material to avoid galvanic reactions between dissimilar metals. Specify isolation material at interfaces of dissimilar metals.

For submerged carbon steel components, the importance of a good coating system cannot be understated. Early coating failures are all too common for treatment plant equipment. Coating problems result in expensive recoating work at best and corrosion or even equipment failures at worst. Robust surface preparation and coating requirements should be specified and enforced during construction.

A good coating system starts with proper surface preparation. Specify all carbon steel surfaces to be sandblasted to a NACE 2/SP-10 profile, also called “Near White Metal Blast”. Wet abrasive blasting or vapor blasting can also create the NACE 2/SP-10 profile, however, the presence of water increases the risk of rust formation prior to prime coating, so it is not recommended for clarifier components.

After blasting, the surface profile does not remain ideal for long. Rust begins to form within 24 hours in dry conditions, and almost immediately wherever water is present. Any rust bloom formation will not allow the coating to adhere properly and it will fail early by blistering and delamination. Consider specifying the following requirements to help “hold the blast” for a successful prime coat:

- Cover the tank before beginning blasting operations. The cover shall be structurally sound with a center support from the clarifier platform. The cover system shall be designed to withstand the forecasted wind conditions. Consult with a structural engineer for additional language regarding wind loads. Provide stormwater drainage from the cover. Provide a ventilation system for the tank. See Figure 35 for examples of covers on clarifiers.
- Hold a conference call or meeting with stakeholders to review details of the proposed surface preparation and coating work.
- Remove all standing water from the tank and maintain the following conditions inside the tank throughout the blasting and coating process: relative humidity below 45% or temperature at least 5 degrees above the dew point. Utilize a dehumidification system and a continuous humidity monitor (aka hygrometer) to confirm compliance.
- Blasted surfaces are to be prime coated within 24 hours. Any surface not coated within this time shall have the blasting repeated.
- Stripe coat all edges, interfaces, and ends of members and plates.

- The coating manufacturer shall review and approve the proposed blasting and coating process. An authorized representative shall inspect the blasted surfaces, the prime coat, and the finish coat, and provide a letter indicating acceptance of the observed surface preparation and coating system.

Figure 35: Example of a tarp cover on a clarifier. The cover functions to provide ideal conditions for blasting and coating carbon steel surfaces and provides dust control.

Existing Drives

If existing drives are to be reused instead of being replaced, they should be protected during construction. During blasting operations, drive units should be protected from airborne sand by wrapping with a plastic cover or similar. See Figure 36 for an example of a drive unit that was not protected.

Figure 36: A drive unit covered in abrasives from sandblasting.

Existing drives should be cleaned as part of the rehabilitation work. It is typically worthwhile to have a qualified mechanical contractor disassemble the drive unit, mechanically clean the internal surfaces with a degreaser, and inspect the gear surfaces, bearings, and parts for potential areas of concern. See Figure 37 for an example.

A lubrication system cleaning should also be specified. The following are options to consider, in order of least to most effective:

- Double Oil Change
- Simple Power Flush (one direction)
- Advanced Power Flush (both directions, high temperature, pulsed flow)
- Chemical Power Flush (solvents added to oil)

Figure 37: Disassembled drive unit for cleaning and inspection.

Construction Tips

Schedule

Early in the construction process, a construction schedule should be developed. Milestones should be defined in the schedule, especially if multiple clarifiers are being rehabilitated. Typically only one clarifier should be worked on at a time. A time period should be allowed between each clarifier to account for startup and testing activities. See Figure 38 for an example schedule.

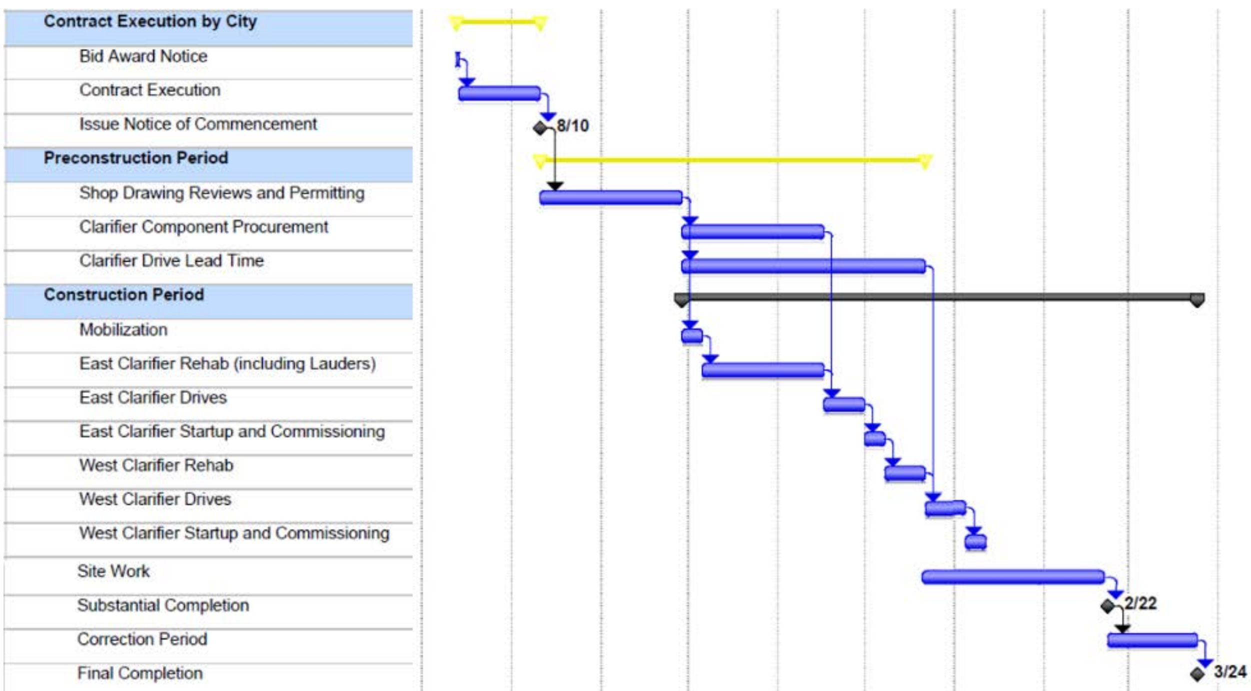


Figure 38: An overall construction schedule for a clarifier rehabilitation project. The clarifier rehab line items should be broken up into smaller tasks.

The start of the rehabilitation work is typically predicated on the equipment lead times. See Figure 39 for typical component lead times. The lead time for a new drive unit can be 20 weeks or more in some cases, so the manufacturer should be consulted.

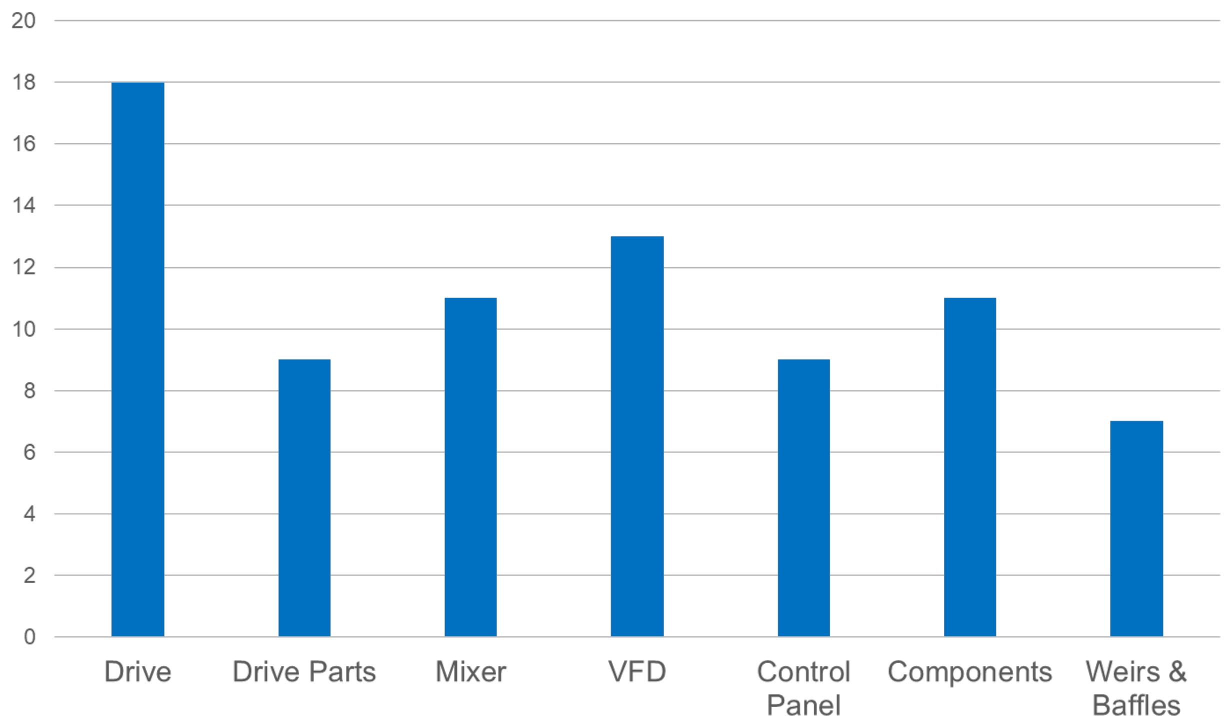


Figure 39: Typical lead time in weeks for clarifier items.

Coating Inspections

As explained in the Design section, the proper application of the coating system makes a big difference in the longevity of the clarifier. Surface preparation is the single most important factor that can make or break the coating system.

It is difficult work for a blasting crew inside a clarifier, but it is of high importance that all surfaces are fully blasted prior to coating. Field inspections help ensure this happens. Confirm that blasted surfaces are kept dry and prime coated within 24 hours. If signs of rusting are observed, have the Contractor to blast the area again. See Figure 40 for an example of a rusted surface.

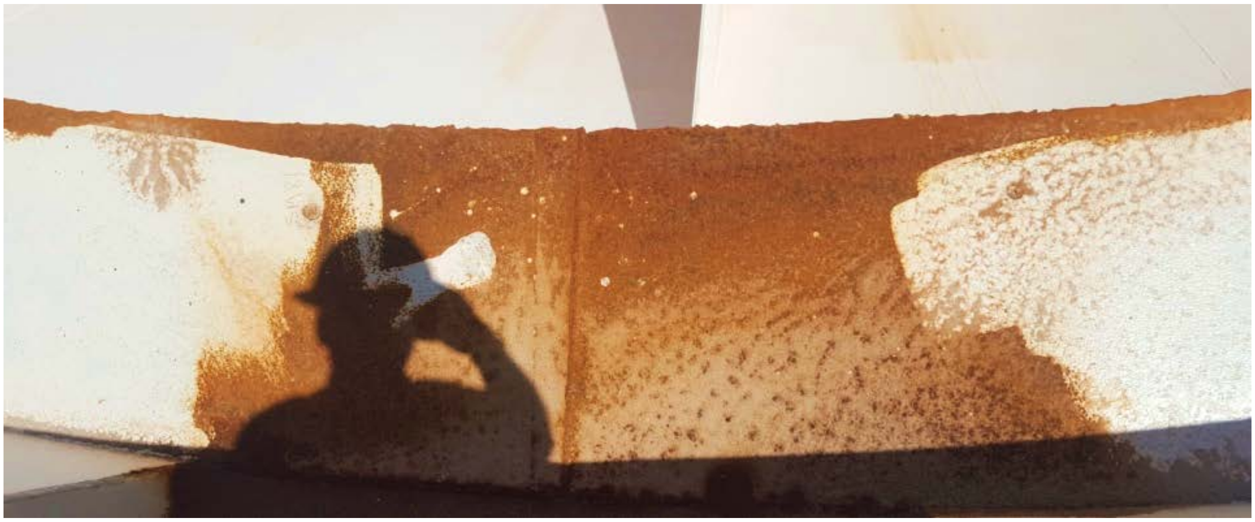


Figure 40: A blasted surface after 5 days, with an area in orange that was not prime coated and has started to corrode.

Most coating failures occur at the following locations:

1) at the ends of members with uneven coating, or
2) at rough welds.

To address number 1, after blasting, the Contractor should stripe coat all edges. Inspect to confirm that all edges have been coated.

To address number 2, inspect that all welds are ground smooth. It is never too late to ask the contractor to grind smooth a weld and touch up the coating afterward.

After the final coating is applied, inspect for full coverage and total thickness. See Figure 17 for an example thickness gauge. Check hard to reach nooks and crannies, such as those shown in Figure 41. Use a ladder as needed to inspect the areas that cant be seen from the walkway or floor. Ladders should be tied off for safety.

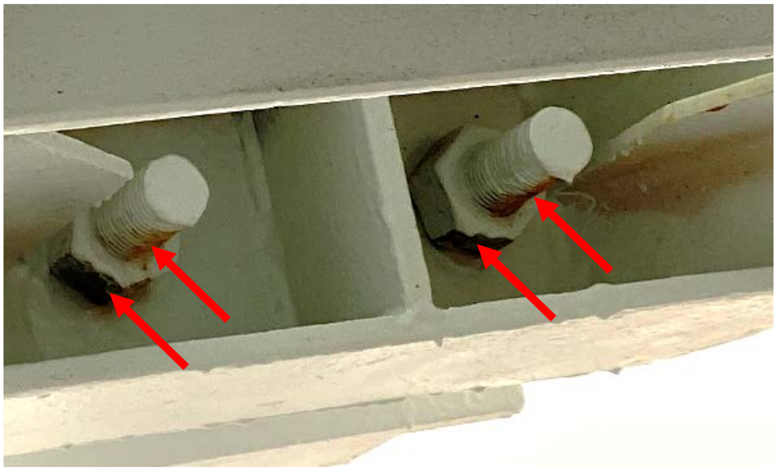


Figure 41: The red arrows point to steel surfaces without proper coating.

<u>Repairs for Thin Steel</u>

After being blasted, the steel will be a little thinner. Typically there is an immeasurable difference in steel thickness. However, in areas of delamination and corrosion, the blasting can significantly reduce the thickness, and even create new holes in the steel. Ideally, thickness measurements would be repeated after blasting and priming. At a minimum, surfaces should be visually inspected and hand-measured to help determine if there are areas of concern.

Thin areas can usually be patched with reinforcing plates that are field welded to cover the areas. See some examples in Figures 42 and 43. The engineer should define the extents of the patching required to cover the thin area. The contractor can cut A36 plating (typically 1/4" thick) and field weld it over the area.

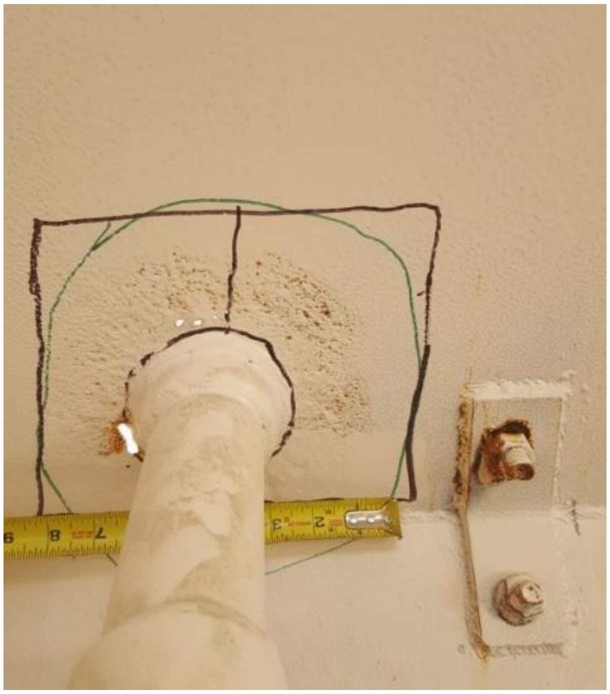


Figure 42: Thin steel discovered near a pipe penetration.
The extent of the recommended reinforcing plate is drawn in black marker.
In this case, two C-shaped plates are required.

Figure 43: On left: Plate with thin areas delineated with black circles and the extents of the reinforcing areas drawn in black lines.
Right: After reinforcing plates were welded to cover the think areas.

<u>Stainless Steel</u>
Stainless steel is chosen because it is naturally resistant to corrosion. However, stainless steel is susceptible to contamination during installation, especially if field welding is done. See Figure 44 for an example. To avoid these problems, some engineers forbid field welding of stainless steel. However, for clarifier rehabilitation work, field welding is sometimes unavoidable.

The key to maintaining the natural resistance to corrosion is to passivate surfaces with acid or pickling paste. The following manufacturers make products for field passivation of stainless steel: Oakite and Avesta BlueOne. Passivation should be done to all field welds and any shop welds showing discoloration. Any areas with carbon steel contamination should be passivated as well. See Figure 45 for an example of welds that have been ground smooth and passivated.

Figure 44: Stainless steel welds with excessive slag and discoloration. Also, note the orange specks of carbon steel contamination.

Figure 45: Stainless steel welds after grinding, smoothing, and passivating.

Helpful References

Wastewater Clarifiers:

WEF (2005) Clarifier Design, 2nd Ed, Manual of Practice No. FD-8; McGraw-Hill.

WEF (2020) Design of Water Resource Recovery Facilities, 6th ed, Manual of Practice No. 8; McGraw-Hill.

Metcalf & Eddy (2003) Wastewater Engineering Treatment and Reuse, 4th ed; McGraw-Hill.

Water Clarifiers:

AWWA; ASCE (2012) Water Treatment Plant Design, 5th ed; McGraw-Hill.

Drive Assessment:

RexNord (1978) Failure Analysis Gears-Shafts-Bearings-Seals, 108-010; Rexnord Industries, LLC, Gear Group.

Field Testing:

APHA; AWWA; WEF (1998) Standard Methods for the Examination of Water and Wastewater, 20th ed.; Washington, DC.

Jenkins, D. M.; Richard, M.; Daigger, G. (2004) The Causes and Cures of Activated Sludge Bulking and Foaming, 3rd ed; Lewis Publishers.

Alternatives Comparisons:

Ludwigson, M.N. (2020) Sustainability Comparisons for All Engineers; SunCam.

