
Elk Valley Water Quality Plan

Annex J.2

Calcite Treatment Technologies



May 16, 2014

REPORT ON

Calcite Treatment Technologies

Submitted to:

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REPORT



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Executive Summary

Golder Associates Ltd. (Golder) is providing support for the development of a plan to mitigate calcium carbonate (calcite) precipitation in streams draining Teck Coal Limited's operations in the Elk Valley. The support is contributing to the identification and evaluation of calcite treatment systems.

For calcite, it is the formation of scale rather than just the concentration of scaling compounds that is of concern to the setting of treatment objectives for the design of treatment systems. The rate of scaling is driven by the rate of gas transfer in the system.

This report summarizes select calcite treatment methods that are designed to run unattended for extended periods, require fewer or no reagents, generate less waste, better accommodate large and variable flows, and require less infrastructure such as access and power. These include:

- Alkalinity reduction;
- Constructed cascades;
- Antiscalants;
- Pond treatment;
- Trickling filters; and
- Ultrafine limestone or Precipitated Calcium Carbonate (PCC).

These potential technologies may be generally grouped as follows:

- Simple reagent addition systems, such as alkalinity reduction or antiscalant systems, that prevent scaling through chemical reactions and inhibition; and
- Gas transfer and solid-contact devices such as cascades, aerators, trickling filters and ultrafine calcium carbonate that mimic, under controlled conditions, the scaling process that naturally takes place in the subject streams.

This report is divided into three parts:

- Background and theory behind the generation of neutral mine drainage and the deposition of calcite, as well as calcite treatment technologies;
- Description of the technologies and design principles; and
- Considerations for technology selection.



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1.0 OBJECTIVES

Golder Associates Ltd. (Golder) was retained to assist in the evaluation of technologies to mitigate calcium carbonate (calcite¹) scaling in streams draining Teck Coal Limited (Teck) operations in the Elk Valley. The assistance included the evaluation of the following calcite treatment methods/technologies:

- Alkalinity Reduction;
- Cascades;
- Pond Treatment Systems;
- Trickling Filters;
- Antiscalants; and
- Ultrafine Limestone or Precipitated Calcium Carbonate (PCC).

The goal of this report is to provide information on the above-listed calcite treatment methods/technologies. The discussion is limited to specific treatment methods and does not include the consideration of additional calcite control measures that may be employed such as changes to dump atmosphere (pore gas), water diversion, seepage control and active treatment (e.g., lime softening).

¹ For the purposes of this report, the term calcite is used to refer to calcium carbonate precipitates in general.



2.0 BACKGROUND AND THEORY

2.1 Neutral Drainage Generation

Waste rock spoils in the Elk River Valley contain a mixture of residual coal, overburden and low-yielding strata consisting mainly of sandstones with some minor coal content. Pore gas within the piles becomes enriched in carbon dioxide (CO₂) and deficient in oxygen (O₂) through normal oxidation of both residual carbon-containing fractions and sulphide minerals in the dump. In some cases, pore gas has been measured at 15% CO₂ or higher (MacGregor et al. 2012). This CO₂ dissolves in the pore water to produce free acid (carbonic acid), which is partly neutralized by carbonate minerals in the spoil pile. The resulting drainage from the spoil piles is high in hardness and bicarbonate, and contains elevated dissolved CO₂.

2.2 Calcite Deposition

As drainage emerges from the waste rock spoil piles, excess CO₂ is released and the pH rises. This causes some of the bicarbonate to convert to carbonate, and calcium carbonate may precipitate. Calcite deposition can result from both natural and man-made processes. In both cases, calcite precipitates from solution when the theoretical solubility limit of the mineral is exceeded. Under certain conditions, a solution may be transiently stable at higher concentrations; this is known as supersaturation, and is the driving force for calcite precipitation.

In solutions of calcium and bicarbonate, the tendency for calcite precipitation increases when the solution pH approaches the point at which bicarbonate (HCO₃⁻) starts to be converted to carbonate (CO₃²⁻). For example, at a pH of 8.0, only about 0.5% of the total inorganic carbon (TIC) in solution is present as carbonate and available for calcite precipitation, but at pH 9.0, that number rises to 4.5%.

Monitoring programs in the Elk Valley show that calcite scaling typically begins some distance downstream of rock drains (Interior Reforestation 2011, Interior Reforestation 2012a, and Vast Resource Solutions 2013). Based on these observations, and as supported by salient literature (Jacobson and Usdowski 1975, and Usdowski et al. 1979), the precipitation of calcium carbonate in such streams takes place in a two-step process:

- Step 1 is the release of carbon dioxide and a rise in pH. Spoil drainage releases excess CO₂ for some distance downstream of the point of emergence from the drain. However, typically only limited scaling is observed close to the rock drain, before gas transfer has had a chance to occur.
- Step 2 is the precipitation of calcite. At some distance downstream, pH reaches a value at which supersaturation is sufficient to precipitate calcium carbonate. This releases acidity (H⁺) which counters the rising pH. From the literature (Fouke, 2011), this supersaturation is a function of temperature; surface area of seed solids; interfering ions such as magnesium (Mg²⁺) or phosphate (PO₄³⁻); biota such as algae, moss and slimes; the level of calcium hardness; and even the water velocity. Thus, the degree of supersaturation will vary from site to site.

For calcite, it is the formation of precipitate rather than only the concentration of precipitating compounds that is the source of concern. The degree of precipitation is driven by the rate of gas transfer (Step 1), which controls the pH, the degree of supersaturation of calcite, and in turn, the rate of precipitate deposition (Step 2).

It is worth noting that calcium carbonate precipitation is documented in streams in the Elk Valley that have not had waste dumps located above them (Golder, 2014). Indeed, the occurrence of naturally occurring calcite precipitation due to conditions present in the Elk Valley is documented and monitored in reference streams as part of the ongoing calcite monitoring programme (Lotic, 2014; "2013 Calcite Monitoring Program").



2.3 Calcite Treatment Theory and Design Considerations

Formation of calcite in streams in the Elk Valley is based on managing either or both:

- the supersaturation of CO₂ with respect to the atmosphere.
- the supersaturation of calcium carbonate with respect to equilibrium.

Important considerations that may be applied to calcite treatment designs in the Elk Valley are as follows:

- The natural attenuation process for solid calcite removal consists of two processes: stripping supersaturated CO₂ with a consequent rise in pH, and precipitation of calcite resulting from a shift in the carbonate equilibrium. The conversion of bicarbonate and the precipitation reaction, in turn, reduces pH. Since CO₂ stripping is more effective at lower pH and calcite precipitation is favoured at higher pH, the two processes are linked and should take place in the same space.
- The saturation index (SI) is an indicator of calcite saturation with respect to equilibrium, and is the most important measure of the tendency for a solution to be scale-forming.
- The degree of calcite supersaturation at which calcite scale starts to form at a significant rate is called the critical saturation index (SI_{crit}).
- SI_{crit} for particular conditions may be estimated by comparing predicted deposition rates for selected reaches with observations of actual deposition from surveys. In such surveys, scale coupons and travertine tiles are placed in the stream to provide surfaces on which calcite may precipitate and be weighed).
- SI_{crit} will vary with the presence of interfering ions such as magnesium cations (which substitute for calcium in the calcite mineral structure) or high-molecular-weight anions (antiscalants) that may adsorb to nascent crystal surfaces and impede crystal growth.
- The shift of the carbonate equilibrium, and the precipitation of calcium carbonate, buffers further pH rise.
- Stream waters are not expected to dissolve existing scale unless the SI drops to negative values, typically below -0.5 to -1.0.
- The precipitation reaction is surface area-dependent, so the overall reaction rate depends both on the saturation index, and on the mass and size distribution of solids in suspension or on the stream bed.
- Adding acid will accelerate CO₂ stripping by shifting the carbonate equilibrium. CO₂ stripping alone changes neither the calcium levels nor the alkalinity levels, but it raises the pH of solutions supersaturated in CO₂, by converting carbonate alkalinity to hydroxide alkalinity. As such, CO₂ stripping raises the degree of calcite saturation, causing calcite to precipitate.
- Stripping of CO₂ from water is governed by the temperature, the surface area of the gas-liquid interface, and the degree of supersaturation with respect to the atmosphere close to the liquid surface. The driving force is dependent on pH, since pH influences the carbonate equilibrium.
- CO₂ stripping depends on dehydration of carbonic acid, but this takes place at a low rate; therefore, the dehydration reaction is the rate-determining step for the overall stripping reaction where gas-liquid transfer is vigorous.



CALCITE TREATMENT TECHNOLOGIES

- Precipitation occurs when the calcium carbonate supersaturation exceeds the enthalpy² for the formation or growth of the solids, and the solution becomes unstable; with low levels of supersaturation, non-precipitating conditions may persist indefinitely.
- Enthalpy is lower for growth of crystals on existing solids, compared to formation of new solid surfaces, so at low calcite supersaturation, the precipitation rate is governed by the amount of solids surface area.
- The flow regime (i.e., turbulence) in natural streams helps dictate both gas transfer and solids contact. This is why natural streams under light supersaturation show variability in the deposition patterns for calcite, with more accumulation typically occurring in weirs and cascades, and less in slow-moving pools and runs (Liu et al. 1995).

Certain calcite treatment techniques such as softening³ through lime addition raise the pH to convert excess dissolved CO₂ to carbonate, thereby precipitating calcium carbonate. The treatment technologies discussed in this report offer the following advantages over softening treatment systems:

- Many sites where calcite precipitation is a concern are located near active spoil piles, which create down-slope hazards and preclude the construction of conventional softening treatment systems.
- Many sites are remote, with limited access to infrastructure such as roads for frequent lime delivery, or power for conventional lime softening equipment; remote sites are also costly to service. The treatment systems considered in this report can be designed to run unattended for extended periods (with only monthly inspections and limited seasonal maintenance). They require fewer or no reagents, and require less infrastructure.
- Conceptual design work has shown that the treatment systems considered in this report can result in an 85% to 95% reduction in waste production compared to lime treatment (Golder 2012c), as well as significant reductions in the quantities of reagents.
- Many drainages have highly variable flow rates, which makes sizing of softening treatment equipment difficult and costly. The treatment systems considered in this report can be designed to accommodate large and variable flows more easily.

It is worth noting that some of the treatment systems considered in this report would also be expected to have an impact on other water quality parameters at specific sites. For example, calcite precipitation is expected to sequester trace amounts of cadmium as a carbonate, which would help manage cadmium concentrations in the receiving environment. In other cases, acid addition treatment may release residuals (chloride, sulphate or nutrients, depending on the acid type) that may not be acceptable to the receiving environment. These and other potential issues are discussed in greater detail in Section 3.0.

² Enthalpy of a reaction is the thermodynamic driving force

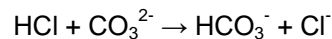
³ In the context of calcite control softening would be defined as the removal of dissolved calcium ions to prevent the formation of calcite.



3.0 TECHNOLOGY DESCRIPTIONS

3.1 Alkalinity Reduction

Alkalinity reduction is widely practised in other applications (e.g., pre-treatment for reverse osmosis, cooling system management and drinking water supply), and has potential for certain Elk Valley streams due to its simplicity and effectiveness. Alkalinity reduction is achieved through the addition of a dilute acid that shifts the carbonate equilibrium preventing calcium carbonate precipitation, and accelerates stripping of carbon dioxide to the atmosphere. With the addition of acid, the carbonate equilibrium shifts according to the following equation (using hydrochloric acid as an example), where carbonate is converted to bicarbonate:



The shift in the carbonate equilibrium reduces the SI of calcium carbonate, and thus the scaling tendency.

Residual ions are a key potential shortcoming of the alkalinity reduction; for example, adding hydrochloric acid leaves a chloride residual. There is a further potential for co-precipitates such as cadmium to be mobilized through dissolution of calcite deposits.

Acid dosage is site-specific and is determined through adaptive management. Dosage metering is based on measurements of pH and conductivity in the treated stream. The metering system includes:

- protective enclosure;
- flow sensing system (weir or velocity and calibration curve);
- acid reservoir complete with level sensing and safety vent, with headspace dry scrubber (if necessary);
- metering pump and delivery hose complete with backpressure valve;
- side stream and static mixer compatible with the heat of dissolution (not required in all cases);
- mixing channel or cascade with serpentine flow path;
- pH and conductivity sensor and proportional control system; and
- backup power supply (solar or remote controlled genset with battery bank), complete with remote telemetry for system alarms and reservoir levels.

A schematic for an acid dosing system is provided in Figure 1. This shows two levels of dilution (a static mixer followed by a mixing channel), which is recommended for managing a viscous acid such as concentrated sulphuric acid.

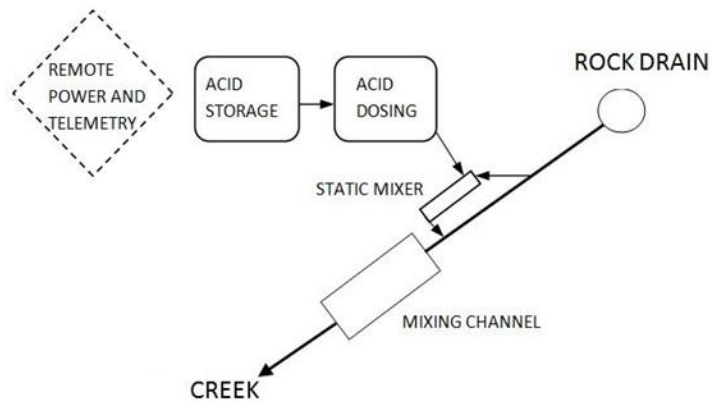


Figure 1: Schematic of an Acid Dosing System

To determine target dosage, it is necessary to develop a calibration curve to correlate pH and conductivity to site-specific water chemistry conditions, through piloting and following a period of adaptive management.

Depending on site access and acid demand, a pre-diluted solution may be delivered to the site, which could eliminate the need for a static mixer. A semi-diluted acid such as hydrochloric may be used, but this would require larger storage facilities. Golder considered three acids:

- Hydrochloric acid (HCl), 35% solution, diluted with feed water in a single stage (more concentrated HCl solutions produce harmful vapours);
- Acetic acid ($C_2H_4O_2$) carboxylic acid, glacial, diluted in a single stage; and
- Citric acid ($C_6H_8O_7$) tricarboxylic acid, diluted in a single stage or in “acid logs”, a slowly-dissolving polymer delivery system.

Each of these acids should be equally effective if properly dosed and mixed with the stream, but each has different costs and downstream effects. A mixture of strong mineral acids and organic acids can also be considered as a means to mitigate the effects of each, depending on the stability of the organic acids at low pH.

3.2 Antiscalant Addition

The addition of antiscalants to supersaturated solutions is considered a viable calcite treatment option for the Elk Valley. Significant effort has been expended by vendors in research and development in this field due to the large and growing market for antiscalant products and a large number of additive formulations are commercially available. The information on antiscalants presented herein was developed from discussions with vendors, and from a literature review.



Precipitation from a supersaturated solution begins when the solution encounters surfaces to which ionic compounds can adhere, thus allowing closer interaction (seeding). Bonds are formed and crystal growth is initiated. In practice, these surfaces may consist of impurities in the solution, or surfaces of the container in which the solution is contained. In a stream bed, calcite deposits grow on rocks and other submerged media, particularly when there is turbulence or a rise in temperature (both which assist with CO₂ stripping), and on natural weir structures (where gas transfer is combined with surfaces).

Antiscalants are chemical compounds that interfere with precipitation by disrupting the formation and growth of calcite deposits through a number of mechanisms as described below:

- **Chelation:** Chelating compounds inhibit precipitation reactions by forming complexes with metal ions. These complexes are known as chelates, and prevent the cation (e.g., calcium) from reacting with an anion (e.g., carbonate) to form scale.
- **Threshold Inhibition:** As crystals begin to form at the submicroscopic level, the antiscalant molecules attach to the positively charged locations and prevent the growth of the crystal by physically blocking further addition of negative ions. This is similar to chelation, but occurs on surfaces.
- **Crystal Modification:** Adsorption of antiscalants on the crystal surface modifies the scale morphology, leading to a weakening of their adherence to a flow surface and a reduction in the speed of crystal growth.
- **Dispersion:** Antiscalant molecules are often formulated to impart an electrostatic charge to the surface of the crystal, repelling crystals from each other to keep them dispersed in the solution.

These mechanisms, which can be summarized as ion activity interactions or surface inhibition phenomena, are achieved by dosing with commercially available antiscalants. Although antiscalants' active ingredients and concentrations are normally the intellectual property of the vendor, Golder believes that knowledge of their chemical makeup will be important to achieving regulatory approval in the Elk Valley.

It is possible to control scale phenomena by adding small amounts (i.e., mg/L range) of antiscalants. Commonly applied antiscalants that inhibit the precipitation of calcite are generally derived from three chemical families: polyphosphates, polyphosphonates and polycarboxylic acids. Typical molecules present in antiscalant formulations include:

- polycarboxylic acid chelants (COOH);
- hexametaphosphate (HMPS);
- polyacrylic acid (PAA);
- 2-phosphonobutane-1,2,4-tricarboxylic acid (PBTCA);
- aminotrimethylenephosphonic acid (ATMP); and
- polyamino polyether methylenephosphonate (PAPEMP).



Antiscalant metering systems are very similar to acid dosing systems, except they use flow and conductivity control rather than pH control. The metering system comprises:

- protective enclosure;
- flow sensing system (weir or velocity and calibration curve);
- reagent reservoir complete with level sensing (the reagent reservoir would likely be smaller than for an acid dosing system);
- metering pump and delivery hose complete with backpressure valve;
- mixing channel or cascade with serpentine flow path to provide mixing;
- conductivity sensor and control system; and
- backup power supply (solar or remote controlled genset with battery bank); complete with remote telemetry for system alarms and reservoir levels.

This is similar to the system illustrated in Figure 1, but with only one level of dilution, with the reagent metered directly to the mixing channel without a static mixer.

3.3 Ultrafine Powdered Limestone Addition or Precipitated Calcium Carbonate (PCC)

Ultrafine powdered limestone addition may be considered in combination with a gas transfer system such as a pond aerator, a cascade, or a trickling filter as a potential calcite treatment option. Ultrafine limestone is normally produced using calcite precipitation, and is also called precipitated calcium carbonate (PCC). PCC is a widely available commercial reagent, and a common additive in the paper industry. Since it has a high specific surface area ($10 \text{ m}^2/\text{g}$ or more), a small dose in conjunction with an aeration system can relieve calcite supersaturation in ponds, cascades or trickling filters prior to discharge. (Use of limestone without a high specific surface area may be ineffective, or may require doses that would make the process impractical). PCC can also inhibit calcite scaling in natural streams by stimulating calcite precipitation in solution rather than on the stream bed. PCC particles are typically on the nano scale (10^{-9} to 10^{-8} m diameter), and resistant to settling out of solution.

This process is best suited to systems that include a cascade or floating aerators for gas transfer, and a settling pond to remove suspended particles some distance downstream of the addition point. PCC would typically, but not necessarily exclusively, be added upstream of settling ponds. However, since the dose of PCC is small, the resulting increase in total suspended solids (TSS) should also be low, and a downstream settling pond may not be required. Work to date (personal communication, M Bratty) has estimated possible dosages using theoretical kinetic relationships, but a PCC system, with either ponds or cascades, has not been bench-tested or piloted. PCC is also suited to application in pond systems with floating aerators (see Section 3.6).



PCC metering systems are similar to antiscalant dosing systems, but use a dry powder delivery system. The system includes:

- protective enclosure;
- flow sensing system (weir or velocity and calibration curve);
- dry powder bag handling equipment (Figure 2) or a hopper complete with screw feeder, delivery pump and wetting head;
- mixing channel or cascade with serpentine flow path to provide mixing;
- pH and conductivity sensor and control system; and
- backup power supply (solar or remote controlled genset with battery bank), complete with remote telemetry for system alarms and reservoir levels.



Figure 2: Example of the Bag Handling Component of a Dry Powder System (graphics by FormPac, Inc.)



3.4 Design Principles for Gas Stripping

Gas stripping is a key element of calcite control, and must be used in conjunction with a solid contact process. In this form of calcite treatment, levels of dissolved CO_2 in supersaturated solution are brought toward equilibrium with the atmosphere.

Gas stripping systems are commonly used in active mine water treatment systems upstream of lime contact systems, to help reduce the lime demand due to the excess dissolved CO_2 . They are designed for (1) high gas-to-liquid G:L ratios in systems where the rate of transfer is relatively low, or (2) low gas to liquid (G:L) ratios for systems where the rate of gas transfer is relatively high.

CO_2 stripping systems for calcite control are an example of case (1), since the concentration difference that is the driving force for transfer is low, and thus the rate of gas transfer is relatively low. Specifically, CO_2 in the liquid phase is low, so CO_2 concentrations in the gas phase must be very low to achieve transfer. Therefore, a large volume of air from the atmosphere must be moved through the system to achieve a measurable rate of gas transfer from liquid to air, and a low content of effluent CO_2 .

Examples of high G:L systems include:

- open spray systems with good air flow;
- open fountain systems or spray-type floating aerators;
- brush aerators; and
- cascades.

Low G:L systems include fine bubble diffuser systems, floating aspirator type aerators, and blower-fed stirred tanks with coarse bubble diffusers. Such systems are not recommended for CO_2 stripping from neutral mine drainage, because they do not efficiently exchange air to reduce liquid CO_2 concentrations.

3.5 Constructed Cascade

Constructed cascades mimic natural streams where calcium carbonate is deposited, by providing aeration and a limited amount of surface area to relieve calcite supersaturation. The benefit of this concept is that it uses the power of falling water to create mixing and gas transfer. Its main weakness is that it is difficult to extrapolate its effectiveness from the pilot to full-scale stage.

These systems are suitable for remote sites that offer the right terrains and topography. They have low or minimal operating cost, but may have higher capital cost than other technologies due to the need for engineered channels.

Cascades may be used with or without the addition of acid, antiscalant, or PCC. As part of a larger technology review (Miranda, 2013), Teck's Advanced Research and Technology group (ART) tested off-gassing through cascades. The degree of gas transfer in a cascade varies with flow, and further evaluation is required to confirm the feasibility of this system for the Elk Valley. However, it may be beneficial to use a cascade system in combination with a reagent for the control of calcite deposition.



3.6 Pond Treatment

Pond treatment should be considered for sites where rock drains feed a relatively large, deep, settling pond and there is access to electrical power.

Pond treatment consists of the following (Figure 3):

- pond aerators to strip carbon dioxide, enclosed in a baffled treatment area;
- dry limestone powder or PCC addition, to provide surface area for precipitation in the same space as the aeration; and
- a low-head feed pumping system to provide a controlled retention time in the treatment area.

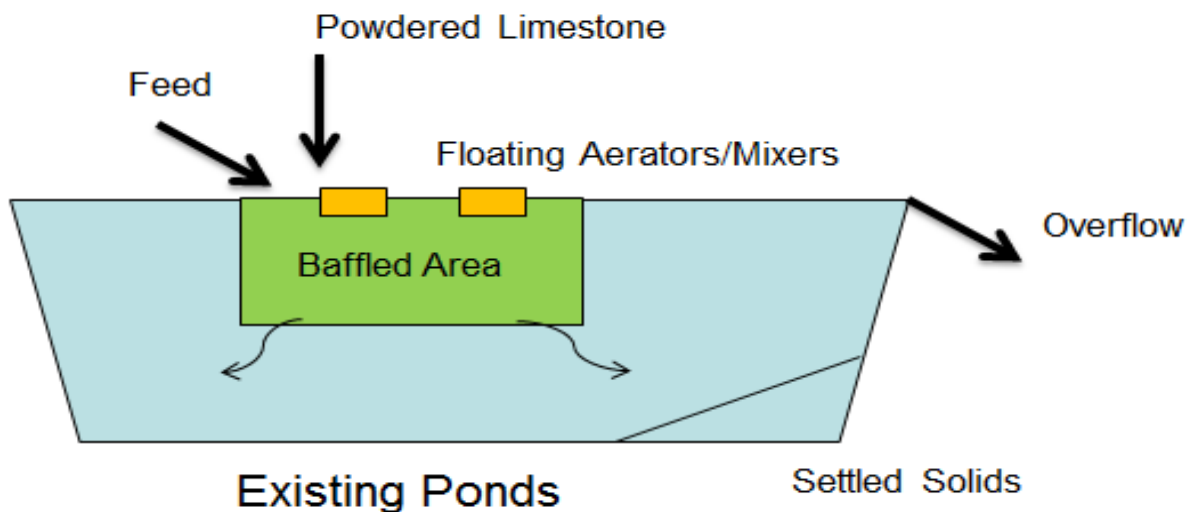


Figure 3: Typical Arrangement for a Pond Treatment System

A typical design consists of a circular baffled area within a sedimentation pond. The required aerator power demand is a function of the size of the baffled area. A typical sedimentation pond may accommodate six or seven floating aerators, each with 20 to 25 kW power. Water is withdrawn from the aerated zone at a controlled rate by means of a low head pump. Trials of similar systems in pit lakes have shown that they provide an effective floating treatment area.



3.7 Trickling Filter

A trickling filter is a solid-liquid-gas contact system that is widely used for sewage treatment. It consists of a ring of aeration media and a water distribution arm that rotates under the power of falling fluid. Water cascades through the media, and in doing so draws air into the bed. After the water has equilibrated with the atmosphere, the calcite is free to precipitate on the solid media and on suspended solids. The media may need to be periodically removed or cleaned as scale accumulates. A typical trickling filter is illustrated in Figure 4.

The benefit of this concept is its potential to provide CO₂ stripping and a large solid surface area in a compact space, without the need for power or reagents (although a feed of PCC could enhance its efficiency and reduce media maintenance).

The main weakness of trickling filter technology is that its use for controlling calcite scaling is still in the early stages of development, and its fundamental principles of operation are just starting to be promulgated; to our knowledge, no trickling filter has ever been applied to a calcite mitigation system. Moreover, the system generates solid waste that requires further management. More bench and pilot testing is required.

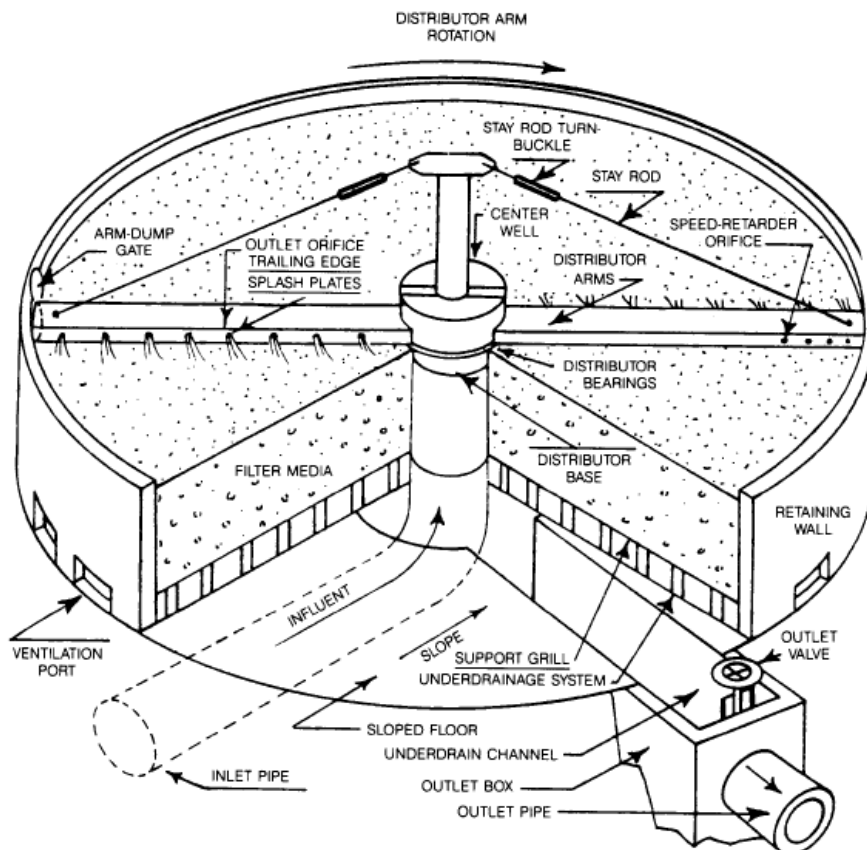


Figure 4: Typical Trickling Filter

Source: EPA 2000



4.0 TECHNOLOGY SELECTION

The treatment technologies discussed in this report are considered to be the most pragmatic solutions currently available for the Elk Valley. Some are proven (e.g., alkalinity reduction), while others have either been shown to work in different settings (e.g., trickling filters) or are proven only in principle (e.g., PCC). The unproven technologies are worthy of further laboratory and/or pilot investigations. It is probable that different technologies, or combinations of technologies, may ultimately be suitable for different sites in the Elk Valley, through consideration of the following site-specific issues:

- the objective for the specific site;
- ecological aspects of the stream in question;
- geochemistry and variability of the calcite source;
- infrastructure opportunities and constraints;
- topography and mine water balance;
- hydrology and water balance;
- logistic aspects of reagent delivery;
- waste generation and disposal;
- maintenance demands;
- process control requirements and the possibility of automation;
- integration of calcite treatment with possible stream rehabilitation initiatives; and
- thorough financial analyses of competing solutions on a total cost-of-ownership basis for the full life cycle of the process.



5.0 SUMMARY

This report provides a summary of select treatment options for the mitigation of calcite precipitation in streams receiving neutral mine drainage from coal mine spoil piles in the Elk Valley. Compared to conventional treatment systems, a different approach to setting treatment objectives is required for the design of systems to control calcite precipitation. Specifically:

- For calcite, it is the formation of scaling rather than the concentration of scaling compounds that is the source of the concern. In natural systems, the rate of scaling is principally driven by the rate of gas transfer.
- The list of technologies discussed in this document does not include all technologies capable of preventing calcite deposition in the streams of the Elk Valley. Listed technologies are considered to be the most pragmatic calcite treatment solutions currently available for the specific conditions in the Elk Valley.
- The selection of the optimal solution will be site specific in each case and will be based on a number of interrelated and dynamic criteria.



6.0 CLOSURE

We trust the above meets your present requirements. If you have any questions or requirements, please contact the undersigned.

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