Steel Processor Wastewater Recycle

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ABSTRACT

The reuse of industrial wastewater is becoming increasingly common because of water shortages, environmental necessities, economic incentives, government mandates, and societal desires. PRO-TEC Coating Company, located in Leipsic, Ohio, is the world's largest hot-dip galvanizing and galvannealing facility producing quality-critical corrosion resistant steel for the automotive, appliance, and construction industries. PRO-TEC successfully implemented recycling of their oily and metal containing wastewater to meet quantitative discharge limits imposed upon them by the EPA. The project provided economic incentive and fit into the company's philosophy of being environmentally friendly.

Keywords: Reuse, wastewater recycling, reverse osmosis, oily waste, metals precipitation, pilot testing.

INTRODUCTION

CROWN Solutions, Inc. was retained to determine what chemical, equipment, and operational strategies would need to be implemented at the site to reduce the discharge of wastewater to the publicly owned treatment works (POTW) from 216,000 – 280,000 to less than 99,000 gallons per day and to create savings by reusing wastewater in the facility.

CROWN evaluated the wastewater treatment for PRO-TEC Coating Company during the summer and fall of 1999. The existing wastewater treatment chemistry was modified and a side-stream pilot plant was operated to determine the chemical and equipment strategy necessary to reuse the wastewater through the existing reverse osmosis (RO) machine. Previous efforts to operate the RO on wastewater had been unsuccessful.

In Phase I of the study, analytical data was gathered to determine influent and effluent characteristics of the present treatment program. Some chemical treatment adjustments and changes were made, and further laboratory analyses were performed.

In Phase II, a side-stream flow of the treated wastewater was taken through an equipment pilot plant. This pilot consisted of a continuously backwashing sand media filter, activated carbon filtration, sodium zeolite water softener, and RO machine. The capacity of the equipment pilot plant was approximately 5 gallons per minute (GPM).

Phase III included a full-stream implementation plan and cost evaluation.

Objectives:

The objectives of the plant management team were to determine a strategy that would reduce the plant's wastewater discharge rate to less than 99,000 gallons per day, meet the discharge limits of the POTW, reuse the treated wastewater as feedwater to the existing reverse osmosis (RO) unit, and improve plant economics.

Considerations included:

1. PRO-TEC had an existing wastewater treatment process that did not produce water of the quality required to feed an RO, however it was a very good process and met discharge limits.
2. There was a limited time frame to meet the deadline of having a system operational.
3. Available space was limited.
4. Capital expenditure limitations were placed on the project.
5. Any system design required contingencies for handling system upsets, it had to be adaptable to changing waste streams, and it had to be expandable.

Pre-existing System Layout:

The plant took in fresh water from the village of Leipsic and retained it in a process water storage tank. The supply pressure was boosted and the water distributed to the various areas of the plant. The primary demand is the demineralizers where the water is passed through activated carbon filters, flows to separate bed cation and anion demineralizers, followed by mixed bed demineralizers. The high purity water is then used on the two continuous galvanizing lines for cleaning the steel strip prior to the coating process. The initial water balance is shown in figure 1.

The wastewater treatment plant collects wastewater in two 150,000-gallon equalization tanks. The cleaners, oils, and rinse waters from the process lines, along with cooling tower blowdown and other wastewaters, mix prior to the chemical/physical treatment process of coagulation, flocculation, gravity separation, and filtration. Ferrous chloride was in use as the coagulant. Compressed air was used to oxidize the pickle liquor to ferric chloride. Sodium hydroxide was used for pH adjustment for metals precipitation. An anionic emulsion flocculant was made down through a blending unit and injected ahead of a floc tank with carrier water.

Initial Water Balance

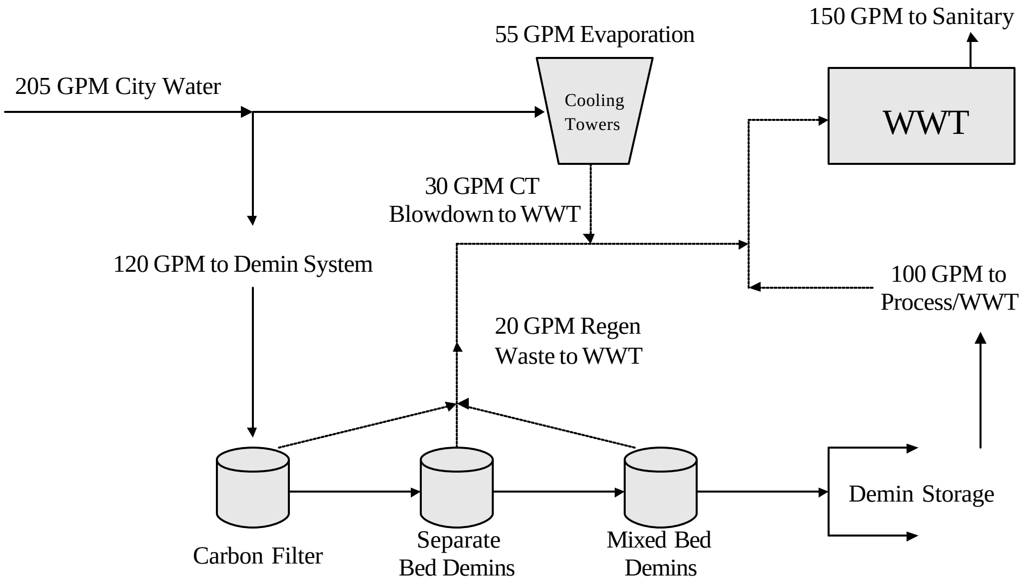


Figure 1.

Water Characteristics:

	City	Treated Wastewater
Conductivity	650 µS	5300 µS
Total Hardness ppm as $CaCO_3$	200	220
Calcium ppm as $CaCO_3$	88	100
Total Alkalinity ppm as $CaCO_3$	35	230
Chloride ppm as Cl	80	Not tested
Sulfate ppm as SO_4	180	Not tested
Silica ppm as SiO_2	6.5	9.6
Iron ppm as Fe	<0.05	1.0
Strontium ppm as Sr	3.5	9.8
Barium ppm as Ba	<0.05	<0.05
Aluminum ppm as Al	0.20	0.6
pH S.U.	8.0	8.5
Oil and Grease ppm	ND	14
SDI	5.0	>10

Constituents of concern for recycling to the RO and meeting POTW Limits:

- Oil and Grease
- Total Suspended Solids
- Microbiological
- Surfactants
- Iron
- Strontium
- Aluminum
- Zinc

Chemical Strategies:

After some thought and jar testing, the following chemical strategies were developed:
1. **Oil and Grease:** Apply ferric chloride and an organic coagulant along with bentonite clay to the reactor tank. Increase and maintain heavy solids level in the reactor tank.
2. **TSS:** Recycle solids to reactor tank. Find the most effective flocculant.
3. **Microbiological:** Sodium hypochlorite
4. **Surfactants:** Coagulants, clay.
5. **Iron:** Replace ferrous chloride with ferric chloride. This eliminated the need for air to the reactor tank and avoided the possibility of incomplete oxidation of ferrous to ferric.
6. **Strontium:** Phosphate precipitation.
7. **Aluminum:** Coagulants and pH adjustment.
8. **Zinc:** pH adjustment.

Mechanical Strategies:

1. **Oil and Grease:** Continuously backwashing sand filter and activated carbon filter.
2. **TSS:** Continuously backwashing sand filter and multimedia filters.
3. **Microbiological:** Ultraviolet radiation (UV).
4. **Surfactants:** Activated carbon filter.
5. **Iron:** Continuously backwashing sand filter, multimedia filters, and sodium zeolite softeners.
6. **Strontium:** Sodium zeolite softeners.
7. **Aluminum:** Sodium zeolite softeners.
8. **Zinc:** Continuously backwashing sand filter and multimedia filters.

Initial Observations:

- Inorganics could be purged from the recycle loop by either sending RO concentrate to the POTW or by sending the pH neutralized demineralizer regenerates to the POTW.
- Water must be evaporated from the loop to meet the discharge limits. Either RO concentrate or treated wastewater must be used in the cooling towers.
- The existing RO was set up to operate on and off by the feedwater tank level. This would need to be changed to be controlled by the permeate tank.
- All piping downstream of the permeate tank was carbon steel, so consideration was given to the corrosivity of the recycle water and consequences.
- The treated wastewater can get hot and may require cooling to stay less than 105°F to avoid damaging the RO membranes.
- The existing process flow included a conical bottom tank to reduce solids in the wastewater. This should be eliminated since high solids are desired for oil and surfactant removal.
- Close control would be necessary to operate successfully.
- Ultrafiltration (UF) or Microfiltration (MF) was not considered due to budget restrictions.

- The existing sand filter after the inclined plate clarifiers (IPC) was badly corroded and was scheduled to be replaced. *CROWN* recommended that the intermittently backwashing filter be replaced with an upflow continuously backwashing filter.

PILOT STUDY

Phase I:

Samples of the raw wastewater were collected from the EQ tanks and after the existing treatment process for analytical data to establish as a baseline starting point. Oil and grease were analyzed by two methods throughout the study. Method 503E is conventional freon extraction with silica gel, which shows most heavy oils and greases. Method 413.2 is an infrared method that picks up more of the low molecular weights and would show surfactants. This method is similar to total organic carbon (TOC).

Provisions were made to treat the entire wastewater flow stream with proposed chemical changes:

a. Compare ferric chloride to ferrous chloride.
b. Feed an organic solution polymer.
c. Feed phosphoric acid.
d. A bentonite clay make-down system was installed to make a 3 - 5% slurry and pump it into the reactor tank.

The first data was collected on August 5, 1999, with the primary coagulant being ferrous chloride. Three more sets of samples were collected on August 9, 11, and 13, and on these days, ferric chloride had replaced the ferrous chloride. Test results showed similar performance in oil and grease removal at lower consumption rates of the ferric chloride compared to the ferrous chloride.

The next three samples collected on September 7, 10, and 17 included treatment with the ferric chloride, bentonite clay, phosphoric acid, and an organic polymeric coagulant.

The next four samples were collected September 29, and October 5, 6, and 11. These four days included the continuation of the chemistry initiated on September 7 with additional samples being collected after the sand filter, carbon filter, and softener with the running of the pilot side-stream equipment.

The data showed that the heavy oil and grease in the raw water influent was relatively low and ranged from 5 to 20 ppm. Oil and grease (method 413.2) showed a range of 31 to 148 ppm.

Strontium in the raw water influent showed a range of 3.41 to 8.09 ppm. It should be noted that analysis of the city water showed a high strontium level of 3.54 ppm. This is likely the source of the strontium in the wastewater.

Aluminum showed a range of 0.19 to 0.50 ppm in the raw water.

To minimize fouling of the RO membranes, it is desirable to have the oil and grease less than 1 ppm and strontium, aluminum, and iron less than 0.05 ppm if possible.

The treatment strategy was to feed phosphoric acid to precipitate strontium, feed clay to absorb the last traces of oil and grease, and use the organic coagulant to help break the oil and surfactant from the water.

Results of Phase I showed that ferric chloride effectively replaced ferrous chloride and reduced consumption from 200-300 gallons/day of the ferrous chloride to an average of 125 gallons/day of the ferric chloride.

The use of the cationic coagulant improved water clarity during times of upset containing high levels of oil and surfactant in the water.

The use of phosphoric acid reduced the strontium level by perhaps 40-50%, but 2-5 ppm of strontium remained, discounting the use of phosphoric acid as an effective chemical treatment method for reducing strontium.

During Phase I of the evaluation, jar testing was conducted to evaluate different clays for the oil absorption and assistance in metal removal. Also another cleaner was compared to the existing cleaner to determine its effect on oil removal. These test results indicated that in the jars, other clays gave similar results to the bentonite clay being used during the trial. The other cleaner chemical applied at similar dosages as the chemical in use to the wastewater showed no ill effect on the oil removal capability.

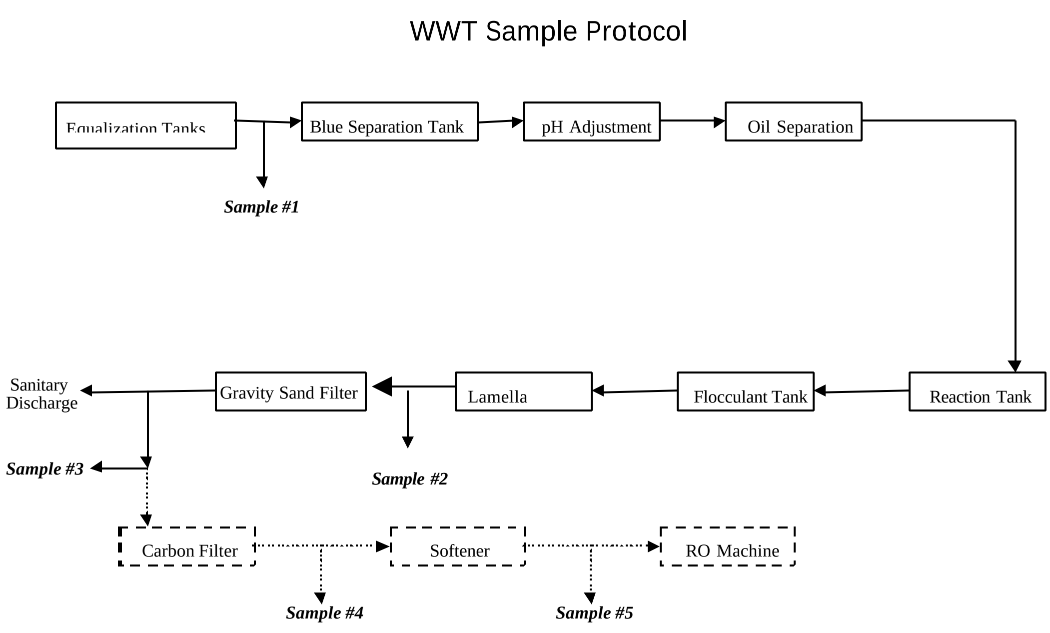


Figure 2.

Phase II:

During Phase II of this study, further evaluation of the chemistry was performed along with the evaluation of the mechanical equipment used for the pilot study. At least two hours were given to allow the treatment to work through this system.

Samples were then collected from the raw wastewater, inclined plate clarifier (IPC), pilot sand filter, pilot carbon filter, and pilot softener for laboratory analyses. Also, Silt Density Indices (SDI) were run at numerous times and recorded. The test results showed that the heavy oil was typically reduced to or below detectable limits by the sand filter. Sample points are shown in figure 2.

Total organic carbon was reduced to approximately 5 ppm after the sand filter, and to less than 1 ppm after the carbon filter.

Aluminum levels were effectively removed by the precipitation in the IPC and filtration by the sand filter.

Strontium required removal by the softeners. Iron was still at fairly high levels of 0.5-0.8 ppm after the sand filters, but effectively reduced to less than 0.1 ppm after the carbon filters.

Total suspended solids were reduced from several hundred ppm (456 ppm on 10/28/99 to 5-13 ppm) after the IPC, and below detectable limits after the sand filter, carbon filter, and softener.

<u>SDI Testing</u>

Silt Density Index testing (SDI) is used to help determine fouling potential for RO membranes. The test procedure measures the initial time it takes to pass 500-ml through a 0.45 micron filter at 30 PSIG of pressure. Flow continues and after 15 minutes, the time is again recorded to fill a 500-ml beaker. Calculations are then made using an index formula. It is desirable to have an SDI of less than 5 units for an RO, and less than 3 is preferred.

With proper pretreatment and filtration, acceptable SDIs were attainable with the pretreatment equipment.

The pilot test data showed that high SDIs were still present after the sand filter. It should be noted that the water from the IPC was pumped to the sand filter. The pumping action will shear any of the floc carryover from the IPC and make the particle size very small. This would be a worst-case scenario, since the recommended equipment strategy would use a gravity fed upflow filter after the IPC.

The SDI profile was 6 to 17 after the sand filter, reduced down to 3.8 to 5.6 after the carbon filter, then further reduced to 2 to 5 after the softener.

We found that the SDI was high when the anionic flocculant was being overfed.

Benefit of Clay

Clay is known to provide additional coagulation and adsorption properties for the removal of oil and grease. The benefit of using clay is in the technical literature. Efforts to determine its effect were made during the pilot trial. SDIs proved to be lower with the addition of the clay.

Microbiological Fouling

During the pilot test equipment operation, it was necessary to feed sodium hypochlorite to the IPC effluent water to control microbiological growth. It was observed that if a chlorine residual was not maintained in the first collection tank, severe microbiological slime growth occurred.

A critical component in maintaining wastewater recycling was very consistent microbiological control of the effluent from the IPCs. For this reason, we recommended both the addition of sodium hypochlorite, and the use of an ultraviolet sterilizing system downstream.

Pilot RO Test Results

The RO machine was operated in an effort to determine effluent water quality and reliability of performance of the membranes. Data was collected regularly throughout the pilot study. Trends on permeate flow, normalized permeate flow, pressure drop across the RO membranes, and percent salt rejection were made.

Permeate flow is greatly affected by feedwater pressure and temperature. Salt concentration also affects the permeate flow.

The normalized permeate flow includes correction factors to consider the effect of temperature, pressure, and dissolved solids.

As would be expected, permeate flow fluctuated up and down based upon temperature and the other factors. Normalized permeate flow also showed considerable variability, showing an up and down pattern.

The pressure drop across the RO membranes actually showed a slight decline over the test period. Fouling would be indicated by an *increase* in the pressure drop.

The percent salt rejection remained very good and actually increased slightly over the course of this study.

The operation of the pilot RO machine along with the other test data suggested that successful recycling of the wastewater was attainable with proper control and pretreatment equipment.

The pressure drop across the carbon filter was also monitored and showed a very negligible increase, suggesting that most of the suspended solids were being removed adequately by the sand filter.

We did find that the softener effectively removed strontium. At times when strontium levels were high coming out of the softener, the softener was in need of regeneration.

Acidic Oil Breaking

With the low levels of heavy oils typically seen during our testing, we felt that there was no benefit from the effort to break oils by initially lowering the pH to 3.5 with acid, which had been the procedure. We did some laboratory testing comparing first adding the acid to lower the pH to 3.5 compared to setting the pH controller in the pH tank at 8.0 - 8.5. The influent oil and grease was reduced from 12 ppm to less than 5 ppm for both scenarios. The total organic carbon oil and grease was reduced from 52 ppm to 10 ppm with the high pH scenario and 8 ppm with the low pH scenario.

Altering the pH set point in the pH tank to 8.0-8.5 would considerably reduce the consumption of acid and caustic.

If heavy oil upsets do occur, the pH set point could be reset on the pH controller to provide an acid break during the upset period(s).

A wastewater solids balance was calculated which showed a major source of the load was from sulfuric acid.

Wastewater Solids Balance

Average Plant Chemical Consumptions			
	Total lbs./day	Demin. Usage lbs./day	Wastewater lbs./day
50% Caustic	3509	3125	384
93% Sulfuric Acid	3744	1710	2034
35% Ferric Chloride	1490		1490

Non-process Chemicals Contribution to Wastewater	**Lbs./day**	**% of Load**
Sodium from caustic	1,009	17.6
Sulfate from acid	3,411	59.5
Chloride from ferric	341	6.0
Minerals from demin	63	1.1
Cooling tower blowdown	906	15.8
Total:	**5,730 lbs./day** *not including process chemicals*	

5,730 lbs./day = 2,655 ppm based upon 180 gpm or about 5300 µS

Phase III (Recommendations):

Chemical Treatment

Ferric chloride provided effective coagulation by itself most of the time. The application of approximately 20-ppm of the polymeric coagulant provided a benefit during upset conditions with high surfactant levels.

The application of clay to the reactor tank provided the benefit of additional solids for the absorption and removal of low levels of oil remaining after the coagulation by the ferric chloride and polymer. The demand varied from 50 to 200 ppm of clay. This would be fed continuously into the reactor tank after being slurried into a feed tank from a supersack and clay feeder system.

An anionic flocculant would continue to be used in the flocculator tank after the reactor tank. Proper control of this is very important to avoid overfeed situations which can lead to fouling problems.

Sodium hypochlorite would be fed into the IPC effluent to maintain a free chlorine residual through the pretreatment equipment prior to the RO. Residual chlorine would be removed with sodium bisulfite.

Sulfuric acid would continue to be used to lower the wastewater influent pH but only to approximately 8.0-8.5 prior to the addition of ferric and caustic to the reactor tank.

An RO antiscalent was recommended to help disperse any remaining contaminants. Product consumption would be very low at 3-4 ppm.

Equipment Strategy

A continuous backwashing sand filter was recommended after the IPC settlers to remove most of the suspended solids. Field experience and our pilot testing showed the sand filter should be followed by a pressure filter containing multimedia with an activated carbon cap. This filter and carbon would remove remaining suspended solids and organics from the sand filter, and provide additional insurance against upset conditions.

The use of softeners after the multimedia filter removes remaining hardness ions, iron, aluminum, and strontium. All of these are potential foulants for RO membranes. This strategy also showed a reduction in SDI and allowed the water to potentially be used in other areas, such as the cooling tower, in the future.

Because of the high microbiological slime problem observed, the use of UV lights was recommended as a sterilant in addition to the chlorine. UV lights would require relatively low maintenance. The light bulbs require replacement approximately once a year.

Recycling wastewater to an RO machine requires very consistent pretreatment, and therefore should offer some redundancy in the pretreatment strategy. The pretreatment equipment that was recommended offers that redundancy.

Automation and Operation

Because there is variability in the waste stream, and the inherent nature of wastewater treatment involves upset conditions, automation should be utilized as much as possible, but close operator attention would be required.

The ferric chloride and polymer blend continued to be fed automatically based upon influent wastewater flow. The clay feed system and the flocculant would also be linked to influent flow to automatically adjust feedrates.

Hypochlorite can be controlled with ORP, a chlorine analyzer, or initially the pump could be pulsed based upon wastewater flow.

Turbidity meters were recommended to monitor for upset conditions from the ICP and/or sand filter. Softeners would regenerate automatically based upon flow, and the multimedia filters will backwash based upon differential pressures.

Full-time operator attention was anticipated for the wastewater treatment, wastewater recycle, and demineralization area. Regular visual inspection of all the equipment and the water itself is required so that immediate action can be taken with upsets or equipment problems. Failure to react immediately can lead to RO membrane fouling and shutdowns.

Some of the major time requirements for the wastewater/recycle program include:

- Maintain all chemical feed equipment and adjust dosages as required.
- Jar test the wastewater regularly.
- Perform various chemical tests, including chlorine residuals, SDIs, and hardness.
- Track RO operating data and the operating data of the other equipment.
- Clean RO membranes as necessary.
- Operate the sludge filter press and control levels of sludge in the ICPs, reactor tank, and sludge thickener tank.

PILOT TEST RESULTS AND RECOMMENDATION SUMMARY

A chemical and equipment strategy was developed that allowed the wastewater effluent to be used as RO makeup water. In addition, dramatic economical benefit was also realized by using the wastewater effluent as a makeup water source to the existing RO machine. The water flow and wastewater flow are shown in figures 3 and 4. The volumetric discharge target from the facility could be realized if these recommendations were implemented. The following is a brief summary of the findings:

1. Test data supported that the ferric chloride could successfully replace ferrous chloride. Dosage could be reduced from 200-300 gallons per day down to 125 gallons per day. The use of an organic polymeric coagulant along with the ferric chloride would be beneficial, especially during times of upsets and high surfactant levels. A 5% blend of organic polymeric coagulant with the ferric chloride was recommended.

2. Jar testing showed that several different clays have some effect on removal of low levels of oil. Also, jar testing showed that a new proposed cleaner had no more detrimental effect on the wastewater treatment than the cleaner currently used.

3. Phosphoric acid provided some reduction of strontium, which is an RO membrane foulant, but was not effective enough to justify its use as a part of the wastewater treatment strategy.

4. Low SDIs were achievable with the recommended chemistry and pretreatment equipment. Typical results were in the 3-5-unit range. High SDIs were seen during periods of overfeeds of the anionic flocculant.

5. The addition of clay to the reactor tank showed beneficial removal of potential organic foulants and was recommended as part of the overall treatment strategy.

6. Microbiological control was extremely important. The water was very slime forming and a free chlorine residual was recommended to be maintained in the effluent from the inclined plate separators. Additionally, the use of ultraviolet sterilization was recommended as an additional method to ensure sterility in the makeup water to the RO machine.

7. The pilot equipment showed the necessity for a multimedia filter containing a carbon cap downstream of the continuously backwashing upflow Parkson DynaSand filter. The sodium zeolite water softener downstream of the carbon filtration equipment provided additional reduction in SDI along with removal of strontium and hardness. In addition, the softener provides redundancy for removal of aluminum and iron. All of these are potential foulants for RO membranes.

8. The data obtained from the operation of the pilot RO showed that an RO can be effectively used to recycle the wastewater with the pretreatment strategy recommended.

9. Testing suggested that it was not necessary to drop the pH to 3.5 in the influent wastewater as an effort to break (help remove) the low levels of oil and grease that are in this water. Operating the initial pH tank at 8.0-8.5 S.U. would reduce acid and caustic consumption. This would further reduce operating costs due to the reduction in acid and caustic necessary to maintain the present pH values in the wastewater system. Also, the reduction of the acid and caustic addition would result in lower conductivity levels in the wastewater, which would further reduce the operating costs.

10. An achievable water balance was attainable to meet the reduced discharge limits. This water balance could be obtained without installing a pH neutralization system for the demineralizer regeneration water. The RO reject will be the primary water discharged to the POTW. Estimated discharge from the facility to the POTW at the present operating rate would be 77,034 gallons per day.

11. As a precaution, if any future plant expansions occur that increase the wastewater flow, a second RO to treat the primary (existing RO) reject would be necessary to maintain the volumetric discharge criteria presently enforced on the facility.

12. It was recommended that the wastewater treatment recycle system be automated as much as possible. Close operator attention would be required to minimize problems and to correct any upset conditions. A full-time operator for the demineralizer/wastewater/recycle system would probably be necessary and was recommended to insure compliance and equipment operability.

Figure 3: Water Flow Diagram

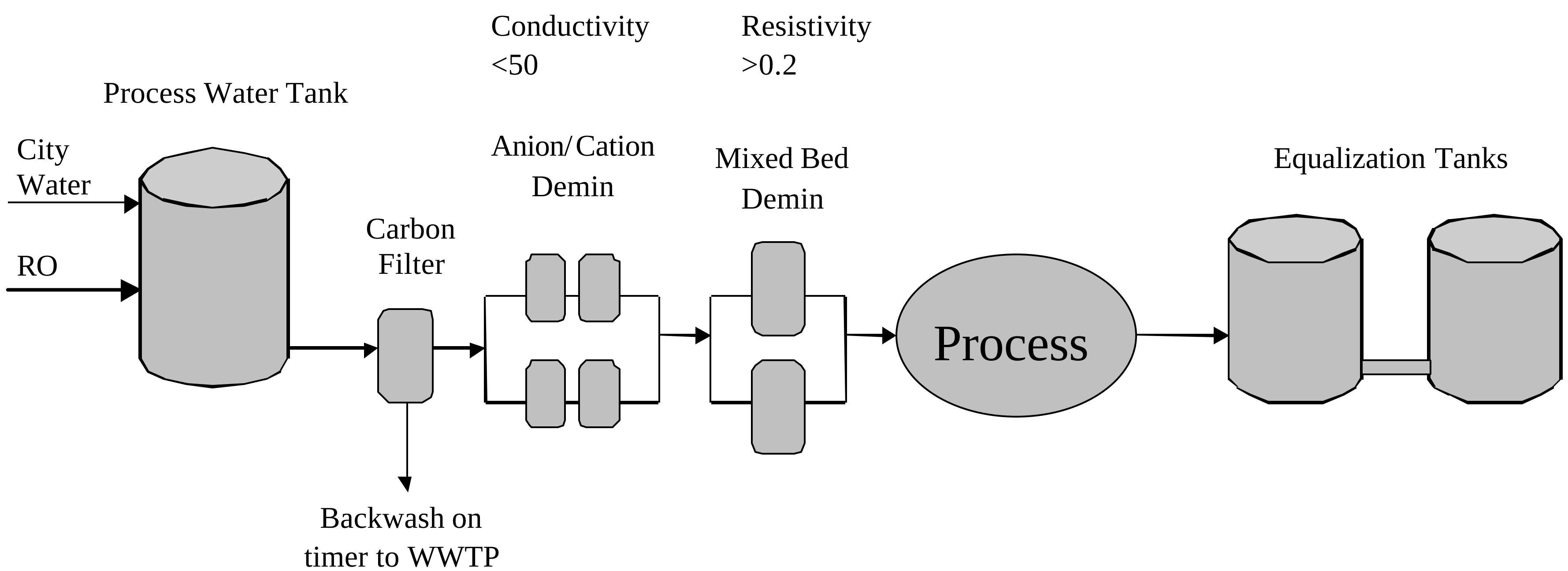


Figure 4-a: Wastewater Flow Diagram

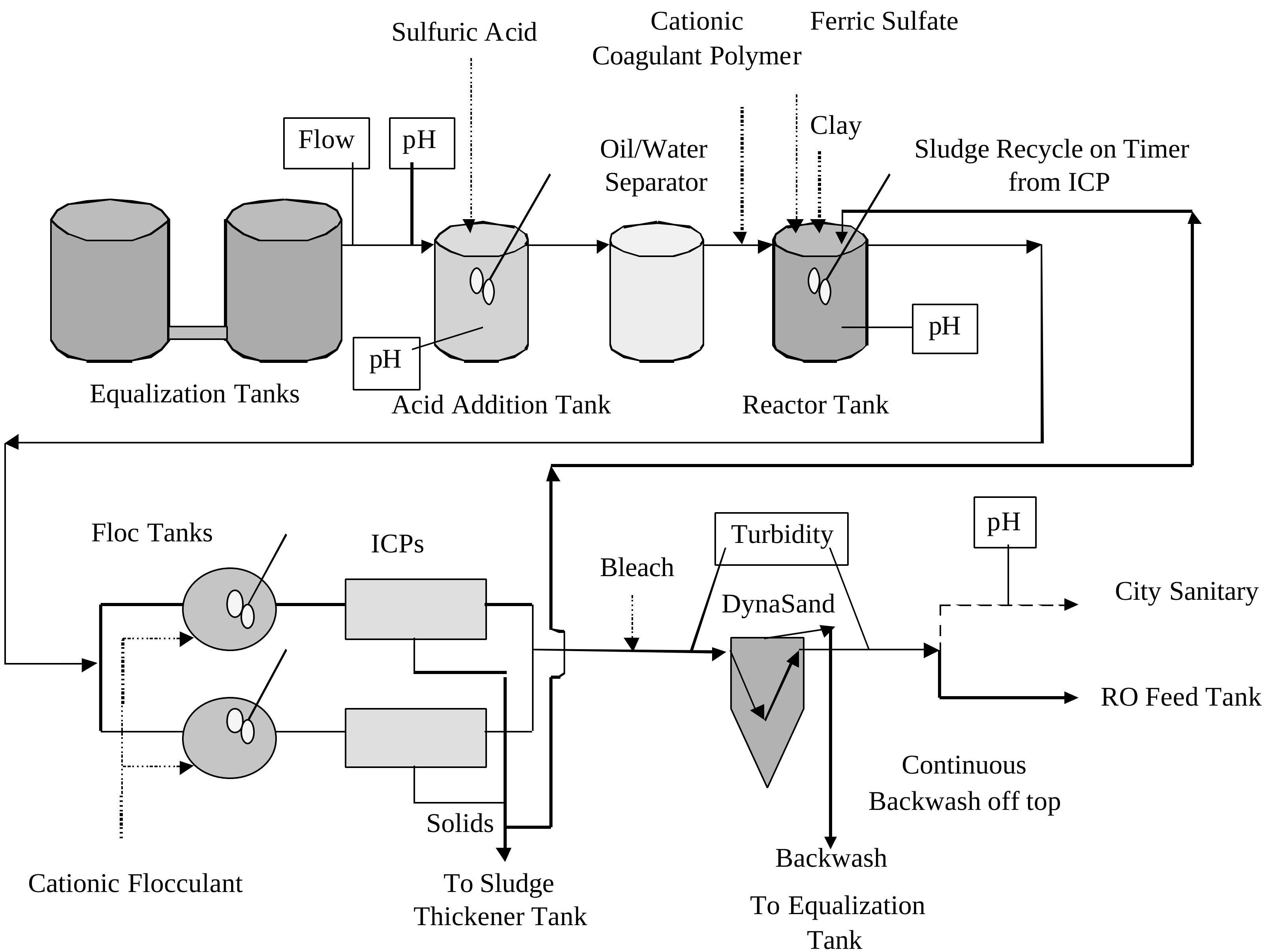


Figure 4-b: Wastewater Flow Diagram

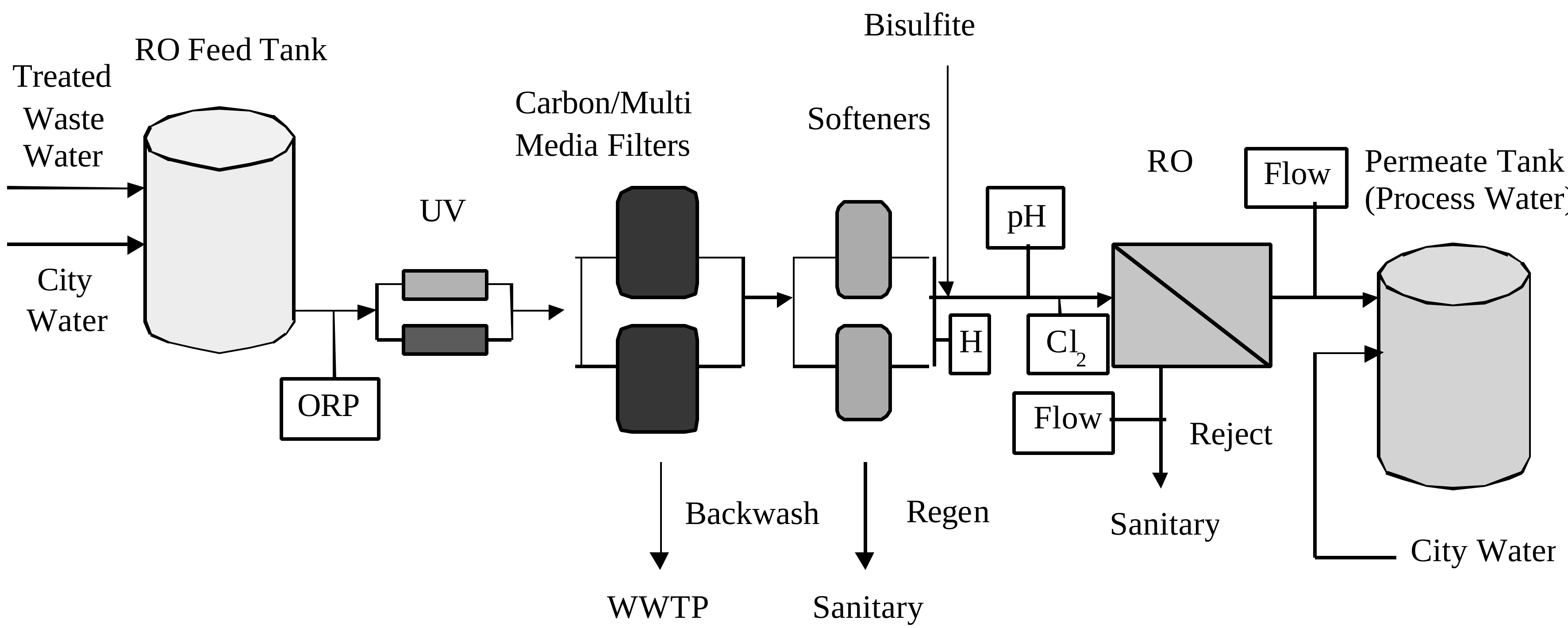
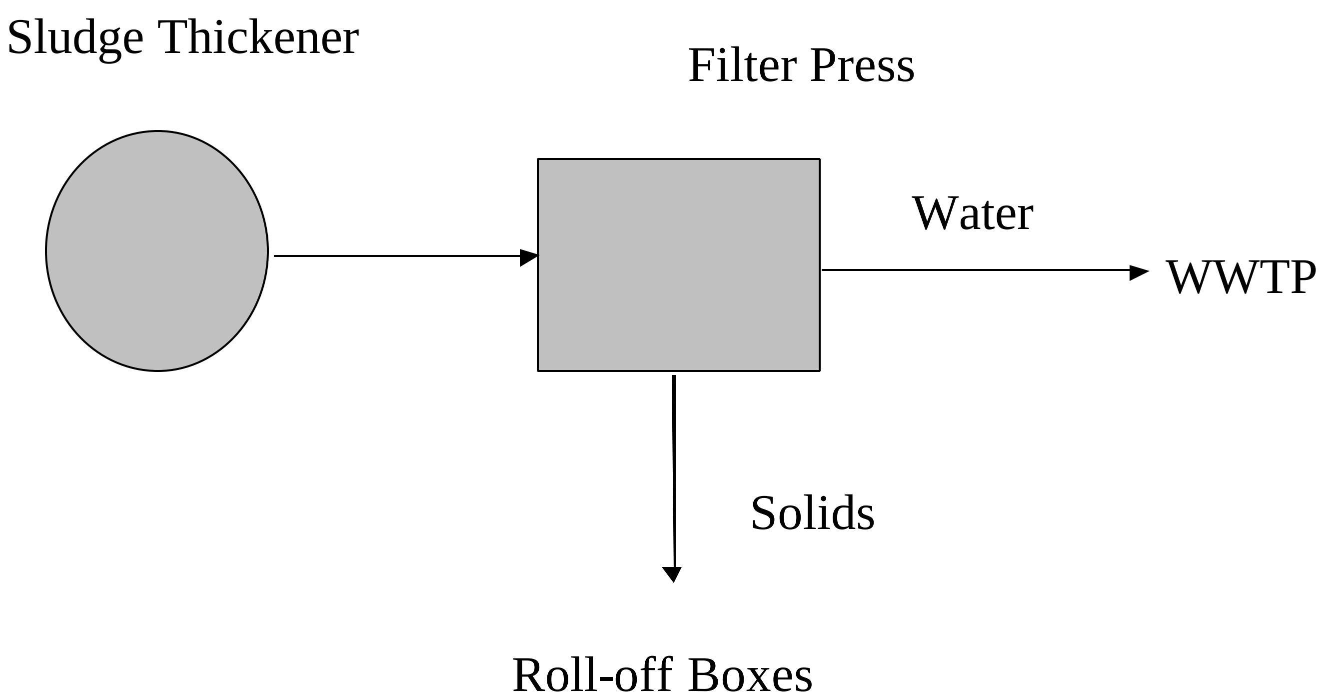


Figure 4-c: Wastewater Flow Diagram



FULL STREAM OPERATION, EXPERIENCE, AND IMPROVEMENTS

A. Standard operating procedures (SOPs) were written and training provided to the plant operators with instructions to look for cause and effects and ways to improve the process.

B. Immediately upon startup, the characteristics of the wastewater changed. Rolling oils at the supplying steel mills were changed. The good clarity of the wastewater that had been achieved during the pilot testing could not be obtained. The use of bentonite clay went from being beneficial to being absolutely necessary. Ferric chloride was replaced with ferric sulfate, which improved results. The organic polymer, which had been mixed with the ferric chloride, was supplied separately to improve flexibility and the necessary dosage was higher.

C. Changing of the wastewater characteristics required resumption of an initial pH depression of the wastewater to 3.5-5.5 instead of where we had been running at 8.0-8.5 or some organics remained.

D. When good results of low turbidity waters of < 1 NTU were obtained, results could change in only a few hours. With equalization tanks, this should not occur. We investigated and found that the valving allowed short-circuiting through the tanks. It was changed to go in the top of one tank, into the next tank, and then out. This provided consistent wastewater characteristics and greatly improved results.

E. SDIs did not predict the reliability of the RO operation or fouling rates. Very high SDIs would be found on very low turbidity waters. The RO was found to operate for months without fouling problems even if SDIs were high or even blanking off. Residual organics could attach to the SDI dead end filter paper, but not adhere to the cross-flow RO membrane

F. A cleaner-dump tank is used to collect concentrated cleaner. It had been piped to pump controlled amounts into the EQ tanks. If the waste became difficult to treat, there was a long lag time to remove the overly concentrated surfactants from the large volume of wastewater. The feed point was changed to allow the cleaner waste to be pumped into the influent to the wastewater treatment plant for quick adjustment control.

G. The concentration of sludge in the reactor tank was found to be very important, so the amount of recycle was more carefully monitored and controlled. The amount found to be effective was at least 20% in a 5-minute settling test.

H. The flocculant addition created a nice agglomerated floc, but fines were still seen leaving the IPCs. The mixer speed was adjusted in the floc tank to optimize results and the top of a baffle in the flocculator tank was cut down to avoid free fall of water that was breaking up the floc. Also the anionic emulsion polymer was changed to a dry cationic. The dry polymer does not contribute surfactant and oil as the emulsion does, and the cationic improved water clarity by capturing more fines. Also the dry feed system that was installed was much more consistent and required less maintenance than the emulsion make-down system.

I. The UV lights were very adversely affected by any color in the wastewater and any bubbles created by the pumping action of the forwarding pump. Foaming from residual surfactants caused low light intensity through the UV cell.

J. An RO antiscalant was used, but found to be unnecessary.

K. The fouling of the RO was found to be residual oils and surfactants and microbiological (MB). 2,2-Dibromo-3-nitrilopropionamide (DBNPA) biocide additions were initiated with 30-minute feedings a few times a week. This greatly reduced MB fouling.

L. The RO clean-in-place (CIP) layout was changed to be able to clean each stage separately. The original system could only clean both stages at once.

M. The RO also gets a monthly shot of about one gallon of caustic into the CIP tank to help clean the RO. The RO is set up to flush with permeate water when the unit shuts down and then the membranes sit in permeate water whenever the unit is off. The procedure seems to be very helpful in keeping the membranes clean.

N. RO cleanings were typically a low pH citric acid based cleaning solution, followed by high pH cleaning with caustic and surfactant. Cleanings were greatly improved by air bumping during the cleaning.

O. The RO membranes had been laid up with sodium bisulfite in the RO pressure vessels for two years prior to being able to practically operate the RO. The polyamide (PA) membranes then lasted two additional years of continuous operation before being replaced because of deteriorating salt rejection. Cleaning frequency had typically been every two months (sometimes more often, sometimes less frequent). An autopsy of one of the replaced membranes showed fouling with oils, bacterial slime, and minerals including the bentonite clay.

P. New PA membranes were installed in April of 2002. It was decided to try 400 square foot membranes instead of the 365 square foot membranes that had been sold with the unit. The new membranes allowed a reduction of flux from 13 gfd to 12 gfd. (Both are much higher than a desirable 5-8 gfd for wastewater applications). This lower flux rate, along with much better control of MB fouling, allowed the membranes to go a year before requiring cleaning. The reduction in brine spacer area did not increase fouling as some experts predicted or other experiences have indicated.

Q. Initially after start-up, there were problems with bacteria creating fouling in the multimedia filters, softeners, and RO. An effective cleaning procedure for the multimedia filters and softeners was to recirculate a caustic solution in a backwash mode followed by the addition of DBNPA biocide.

R. Recently, recycle of the RO concentrate was initiated in an effort to improve recovery of the RO machine from 75% to 80%. We targeted a concentrate flow rate of 20 gpm in the eight-inch housings to minimize fouling.

S. System flow balances have been adjusted to minimize on/off operation of the RO.

T. The objectives, including quantitative discharge limits to the POTW, have been met.