Optimal Chemical Dosing and Backwash Recycling

for the Bozeman Water Treatment Plant

prepared by:

Ellen Lauchnor, Associate Professor, Environmental Engineering, Montana State University; Lura Johnson, Undergraduate Research Assistant; Jack Shonka, Undergraduate Research Assistant

prepared for:

Jill Miller, Superintendent

Sourdough Water Treatment Plant

City of Bozeman, MT

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Executive Summary

This report summarizes the results of the 2021-22 Community-engaged And Transformational Scholarship (CATS) project between the City of Bozeman Water Treatment Plant and the students in the Fall 2021 semester of EENV 341: Chemical and Physical Treatment Processes. The project aimed to investigate the optimal chemical doses for the sludge handling, flocculation, and sedimentation processes at the Bozeman water treatment plant (WTP). Another goal of the project was to test whether adding backwash water from the membrane filters to the influent water stream affected the efficiency of the flocculation process. Jar tests were completed in the lab simulating different influent water conditions. Jar testing simulating the settling of settling in wastewater from the Bozeman WTP showed that the optimal dose of polymer for sludge handling was 5 mg/L. The results for the optimal coagulant dose testing for flocculation and sedimentation of raw influent showed that variables such as temperature and settling time played an important role in the optimal dose, and the data did not yield a specific optimal dose. Despite the inconclusive data, no data was found to support the Bozeman WTP deviating from their current aluminum chlorohydrate (ACH) dosing. During jar testing trials, the addition of backwash water was tested compared to samples without backwash to examine the effect on the efficiency of the pre-treatment process. In general, the results showed that adding backwash water to the influent water made the effluent water more turbid than water with no backwash added and that the optimal chemical dose did not increase but resulted in slightly more turbid effluent water. Overall, there was no data to indicate that the addition of backwash would harm the pretreatment process. It is recommended that 5 mg/L of polymer should be used for sludge handling, and the optimal coagulant dose and backwash dose should be adjusted based on influent turbidity. For future testing at the Bozeman WTP, the settling time after mixing should be increased to four hours, the water sample added to the jars should be completely and continuously mixed at consistent speeds, and the tests should be performed at constant temperature to decrease the variability in the tests.

Background

Figure 1 shows the process flow of water at the Bozeman WTP. The first step in the treatment process is coagulant addition prior to the rapid mix stage. After rapid mixing, the water goes through flocculation, where the water is mixed at decreasing velocities through the flocculation tanks to create clumps of solids (flocs) that settle out in the sedimentation tank. The coagulation, flocculation, and sedimentation processes make up the pretreatment process. Polymer is added to the sludge from the sedimentation basins to dewater and compact the resulting sludge, decreasing the total volume handled, while sending the water through the gravity sludge thickener. Dewatering the sludge helps conserve water and makes the removal of the sludge more cost-effective, as excess water is heavy and expensive to remove.

The water taken out of the sludge is recycled back to the pretreatment process. Prior to filtration, water is pumped through strainers to remove large objects passing through the flocculation and sedimentation steps before filtration. Without this step, solids like pine needles and other organic matter may damage the membrane filters. The water is then filtered using membrane filters, which are backwashed regularly to preserve the effectiveness of the filtration step and to prevent damage. As a result, this backwashed water captures the particulates filtered by the membranes and takes them to the sludge settling basins (Figure 1). This practice wastes water by allowing it to evaporate out of sludge cakes. By utilizing backwash water, water resources can be better conserved.

The backwash water is cycled through the DAF (dissolved air floatation thickener) unit where the solids are removed and the free water is recycled back through to the pretreatment process, similar to the water from the gravity sludge thickener. In examining the possibility to recycling backwash water to the pretreatment process, this step would be skipped, and the backwashed water would be pumped to the raw water in fluent stream prior to coagulant addition. Lastly, the water is disinfected after filtration before it is delivered to the consumer.

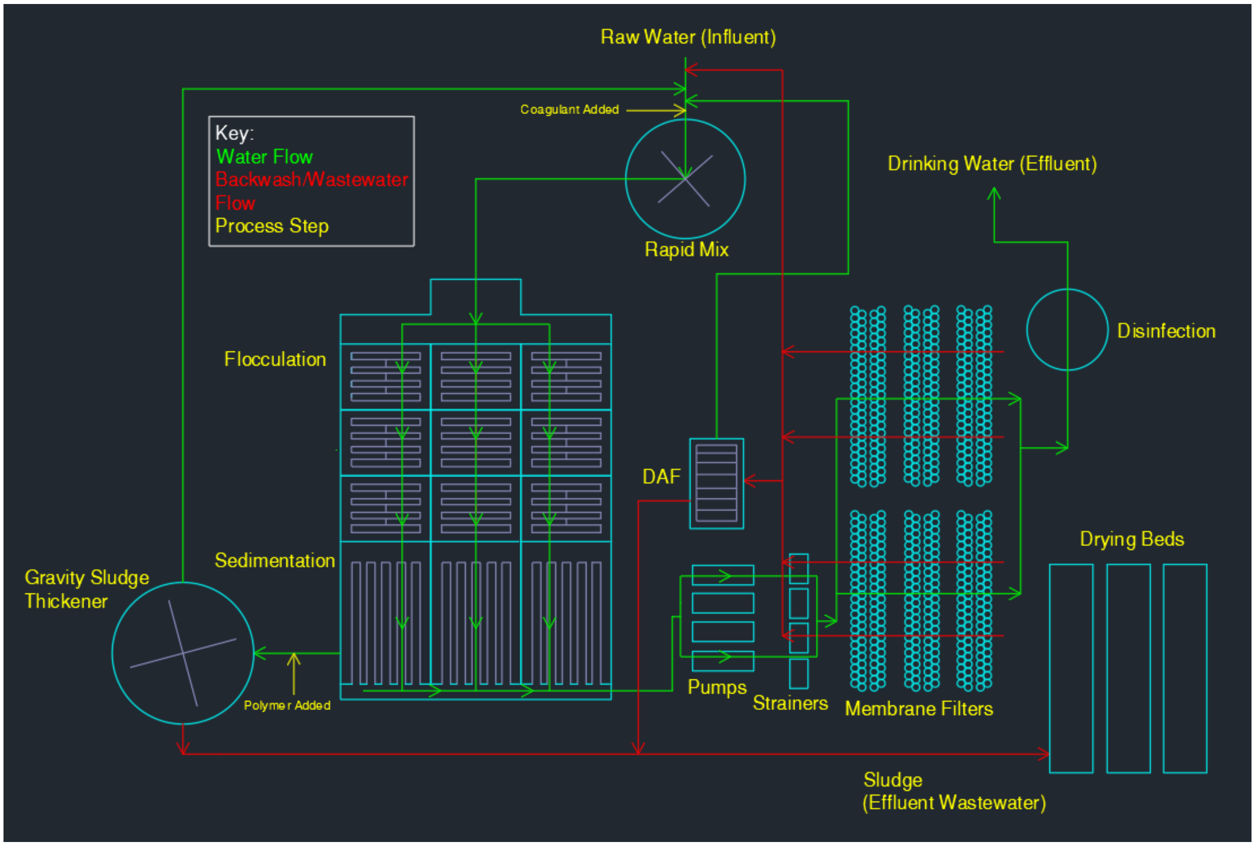

Figure 1: Water Treatment Process and Design

Purpose

The purpose of this project was to report the results of laboratory trials testing the efficiency of current sludge handling and flocculation processes. These processes were tested to find the optimal dose of chemical to add in each step. In addition to finding optimal chemical doses, tests were conducted to see if adding backwash water would impact the efficiency of flocculation and sedimentation.

Sludge Handling

Polymer is added to sludge to increase the compactness of sludge cakes as they settle, prior to disposal in the drying beds. The polymer used in sludge handling helps dewater sludge to conserve water and make the removal of waste more efficient. If there is not enough polymer added the particles will not settle out of the solution efficiently and will not satisfy the Bozeman WTP's efficiency requirement. The Bozeman WTP requires that during the 4-minute period directly following the addition of polymer to a jar with hydrated sludge, that the sludge settles by at least 50% of the total jar volume. If this is not met, it would result in breakthrough of sludge in the water reentering the pretreatment process. If there is too much polymer added the particles will clump together into larger particles that will not settle out compactly because they have a poor shape factor, and the sludge cake appears “fluffy”. Poorly compacted sludge cakes can disperse back into the water, increasing the suspended solids in the water recycled to the pretreatment process.

Backwash Addition and Coagulant Dose

This study aimed to evaluate the impact of backwash on coagulation and pre-treatment. The coagulation agent, ACH, is an aluminum salt that dissolves in water and interacts with colloids to assist in the formation of suspended flocs that are larger than colloids and therefore able to settle out of the water due to gravity. Inorganic coagulation agents, including ACH, are usually expensive chemicals that are best used for low influent turbidities, which highlights the necessity of optimizing dosage for water treatment processes according to state and federal regulations (WIOA, Retrieved November, 2021). ACH is one of the first coagulation agents of choice due to its lower cost than other coagulation agents and its availability relative to other chemicals (WIOA, Retrieved November, 2021). When the new water treatment plant was built, a flocculation and a sedimentation basin were added to help deal with the wide range of influent turbidities that the Bozeman WTP experiences. The WTP currently uses a one-to-one ratio dose of ACH concentration to influent turbidity, with a unitless multiplier to optimize the organics removal in filtration by adjusting the organics removal in the pretreatment process. This allows a constant influent turbidity to the membrane filters of 0.5 (±0.2) NTU, which allows the membranes to function without overloading.

In theory, water used to backwash the filters can be added to the influent water to recycle it and increase initial turbidity to make the flocculation and sedimentation process more efficient. When the influent stream has a very low turbidity, a mechanism called sweep flocculation can occur when the ACH added cannot effectively react with colloids due to their low concentration, and instead precipitates out of the solution. In this case, the addition of more ACH results in a higher turbidity instead of a lower one. With the addition of backwash and the subsequent increase in influent turbidity, sweep flocculation can be minimized, and the number of colloids is increased, therefore reacting more effectively with ACH to settle out of the solution. Overall, switching the flocculation mechanism from sweep to normal flocculation would increase the efficacy of ACH addition and decrease the effluent turbidity. By recycling backwash water to the pretreatment process, the load on the drying beds would also be decreased, conserving water and lowering transportation costs.

This report examines whether this dose is effective at its current state, and how the addition of backwash to the pretreatment process to reduce stress on the drying beds would impact the pretreatment process. The coagulant dosing was tested at a cold temperature and room temperature to compare the actual influent water in the WTP, to standard testing conditions at the WTP.

Methods

Temperature, ACH Dose, and Backwash influence on Turbidity Testing

Table 1: Treatment Conditions for Additional Jar Testing

Trial and Batch #	Temperature	Backwash?	Coagulant Doses
1- Water Batch 1	70°F	N/A	(3) 0 mg/L, (3) 1 mg/L
2- Water Batch 1	70°F	N/A	0, 1, 2, 3, 4, 5 mg/L
3- Water Batch 2	70°F	4%	0, 1, 2, 3, 4, 5 mg/L
4- Water Batch 1	40°F	N/A	(3) 0 mg/L, (3) 1 mg/L
5- Water Batch 3	40°F	N/A	0, 1, 2, 3, 4, 5 mg/L
6- Water Batch 2	40°F	4%	0, 1, 2, 3, 4, 5 mg/L

Jar tests were conducted to test optimal coagulant dose at two temperatures, as well as with and without backwash. In each jar test, six rectangular jars, filled with 1L of sample influent water from the Bozeman WTP were placed into the mixing apparatus. When backwash was being utilized, 960 mL of influent water and 40 mL of backwash water were mixed to generate the 4% backwash concentration desired. Once the corresponding coagulant doses were added to the jars, a flash mixing period of 45 s at 300 rpm was conducted. Immediately after the conclusion of the rapid mix, a 15-minute mixing period at 130 rpm was performed. After the second mixing period, a third at 90 rpm for 15 minutes was performed, and finally, a mixing period at 34 rpm for 15 minutes was performed. Next, the samples were left to settle for 45 minutes. After the 45-minute settling period, 15 mL samples from the water surface were collected and measured in the turbidimeter. Following a cumulative settling time of four hours, water surface samples were taken and measured in the turbidimeter. The data was then recorded. In the case of unexpected readings, the sample was remeasured in the turbidimeter. If the results continued to seem erroneous the measurement vessel was cleaned and a new 15 mL sample was drawn from the water surface to identify whether the original reading was an anomaly or was representative of what was occurring in the jar after settling.

Two tests for jar testing variability were conducted, one at room temperature and one in the cold room. Samples without ACH addition and with 1 mg/L ACH addition were tested in triplicate, and the turbidity was recorded at the 45-minute and 4-hour settling times. The coefficient of variance (COV) was calculated by dividing the standard deviation of each triplicate test by its mean. For variability, a COV of 10 percent or less was desirable between triplicates, while a high COV was desired to correlate ACH dose to a change in turbidity.

During the fall of 2021 when initial student testing was conducted, there was a high degree of variability in jar tests at the specified conditions. To address the variability and to provide optimal coagulant dose recommendations, six jar tests were performed after the initial student testing. Table 1 houses the six treatment conditions utilized during the tests, along with the batch of water that was taken from the treatment plant.

The main variables that were tested were inherent test variability, temperature, settling time (45 minutes and 4 hours), the addition or withholding of backwash (4%), and varying coagulant dose additions.

Sludge Settling Testing

Tests that were conducted to determine the optimal dosage of polymer for sludge settling in the gravity thickener occurred at 70 °F and required two rounds of tests to find an optimal concentration. The first round of tests took sludge water samples and exposed them to 0 (control), 2, 5, 10, 15, 20 mg/L of polymer. The pass/fail condition of solids settling by 500 mL (or fifty percent) or more in a 4-minute period was utilized as prescribed by the Bozeman WTP specifications. The second round of tests was carried out after determining which dosage range from the first round was most effective to pinpoint the most effective dosage. A flash mixing period of 60 seconds at an impeller velocity of 150 rpm was utilized prior to the start of the 4-minute mixing period.

Results

The full results from both student and additional testing can be found in the Appendix.

Influent Turbidity and Test Variability

Three different samples of influent water from the Bozeman WTP were utilized for the additional jar testing in Spring 2022. See Table 1 for the testing conditions and water samples used. The influent turbidities of each water sample tested before addition of backwash or ACH is shown in Figure 2.

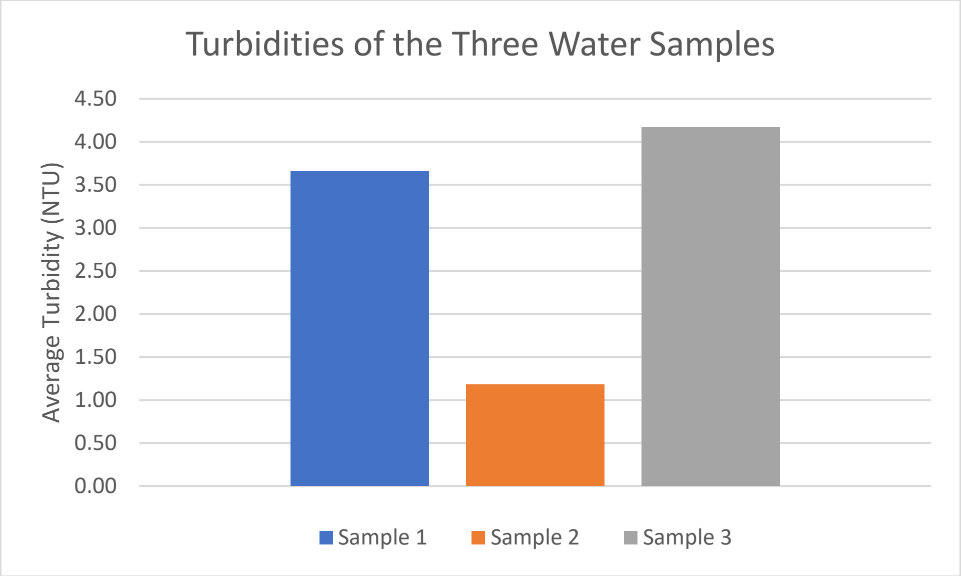

Figure 2: Turbidities of the Three Water Samples. This figure shows the influent turbidities of the three water samples prior to chemical or backwash addition.

Samples 1 and 3 have similar influent turbidities but are significantly higher than sample 2. Caution should be used when comparing tests utilizing sample 2 with the other two samples, such as backwash vs. no backwash, as the influent turbidity can affect the results of the tests. The turbidity readings of sample 1 ranged from an average daily reading of 2.65 NTU to 4.64 NTU, sample 2 ranged from 1.04 NTU to 1.31 NTU, and sample 3 was only measured for one day, with an average of 4.17 NTU.

To test inherent test variability, a COV of 10% or less between the triplicates was deemed an acceptable variation in the test. The results are shown in Table 2.

Table 2: Variability Test Results

			Mean	Standard Deviation	Coefficient of Variance
Room Temperature	45 Minutes	0 mg/L	1.06	0.113	10.70%
		1 mg/L	0.50	0.253	50.94%
	4 Hours	0 mg/L	0.94	0.036	3.79%
		1 mg/L	0.36	0.026	7.36%
Cold Room	45 Minutes	0 mg/L	1.66	0.045	2.71%
		1 mg/L	1.46	0.137	9.40%
	4 Hours	0 mg/L	0.98	0.009	0.97%
		1 mg/L	0.41	0.083	20.31%

Table 2 shows the variability tests performed, and their resulting coefficients of variance. A COV of 10% or below was deemed an acceptable level of variance. The darker green the color, the lower the variance, and the darker red the color the higher the variance.

The variability results indicate that the variability is higher with the addition of ACH versus natural settling without ACH. In general, the cold room shows lower variability than room temperature, with some outliers in the data for 1 mg/L doses sampled at 45 minutes at room temperature and 4 hours in the cold room. Overall, the tests had an acceptable variability, except for these outliers. Through these results, the jar testing method was deemed acceptable to use for this report.

Settling Time

Samples for each jar test were taken at both 45 minutes and 4 hours, to determine the effect of settling time on effluent turbidity. At the Bozeman WTP, the 4-hour settling time is representative of the sedimentation process, while the 45-minute settling time represents jar testing conditions. Generally, the 4-hour settling time provided lower effluent turbidity readings than the 45-minute settling time, meaning more settling had occurred over the longer time period. An example of this result is shown in Figure 3, where the 45-minute readings are consistently higher than the 4-hour readings.

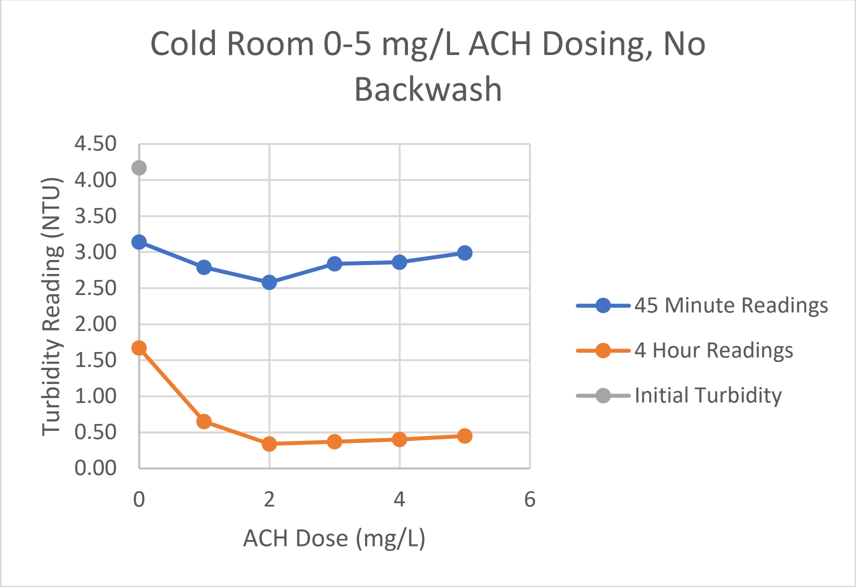

Figure 3: Settling Times for the Cold Room, 0-5 mg/L ACH, No Backwash

This figure shows the difference between the settling times in the cold room.

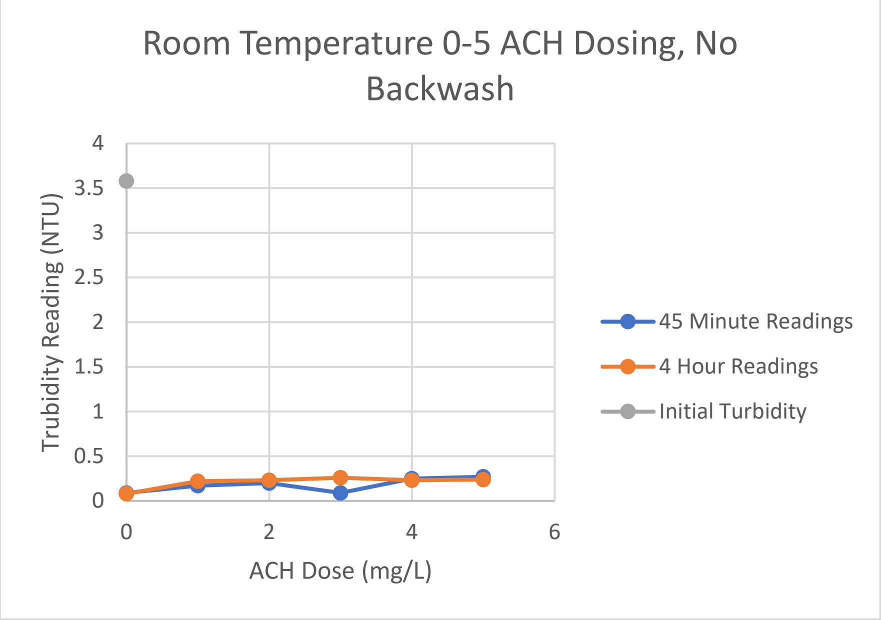

Figure 4: Settling Times at Room Temperature, 0-5 mg/L ACH, No Backwash

This figure shows the difference between the settling times at room temperature. In comparison with Figure 3, the effluent turbidities of the settling times at room temperature seem to be more variable.

The cold temperature testing displayed higher degrees of settling, and more precise results for the optimal ACH dose, while room temperature tests displayed variability in the settling times. This can be seen in a comparison between Figure 3 and Figure 4. An explanation of this variability can be found in the Temperature Variability section.

Temperature Variability

The tests performed at room temperature to simulate the Bozeman WTP testing scenario are compared to the tests performed in the cold room to simulate the actual WTP conditions in Figure 5 and Figure 6 (with and without backwash). In the room temperature testing, water samples were stored in the refrigerator until testing, and then stirred to simulate taking a sample from the influent water stream at the WTP as done during WTP jar testing. In this case, the water was still slightly chilled at the 45-minute reading and was gradually allowed to warm through the 4-hour sampling period. In comparing Figure 3 and Figure 4 in the Settling Time section of the report, it can be seen that at room temperature, the lowest effluent turbidity at either 45 minutes and 4 hours varies from sample to sample. It is proposed that as the sample warms in the room temperature testing, the settling characteristics change over time, resulting in variable settling rates and resuspension, while in cold testing, the temperature remains constant, and results in consistently lower effluent turbidities over longer periods of time (4 hours), as expected.

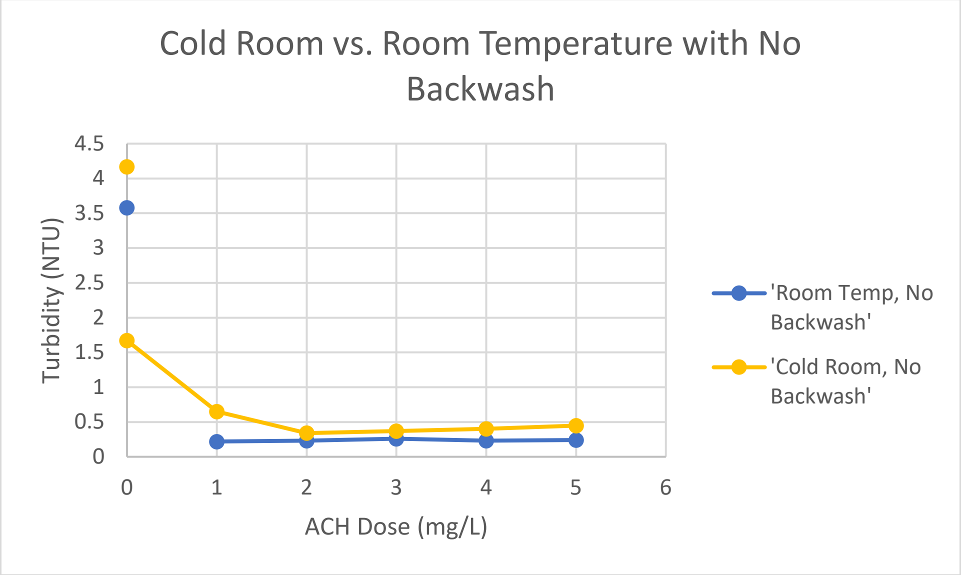

Figure 5: Cold Room vs. Room Temperature with No Backwash

This figure compares 4-hour settling turbidity measurements of the cold and room temperature with no backwash. The initial turbidities are displayed as separate points for each temperature.

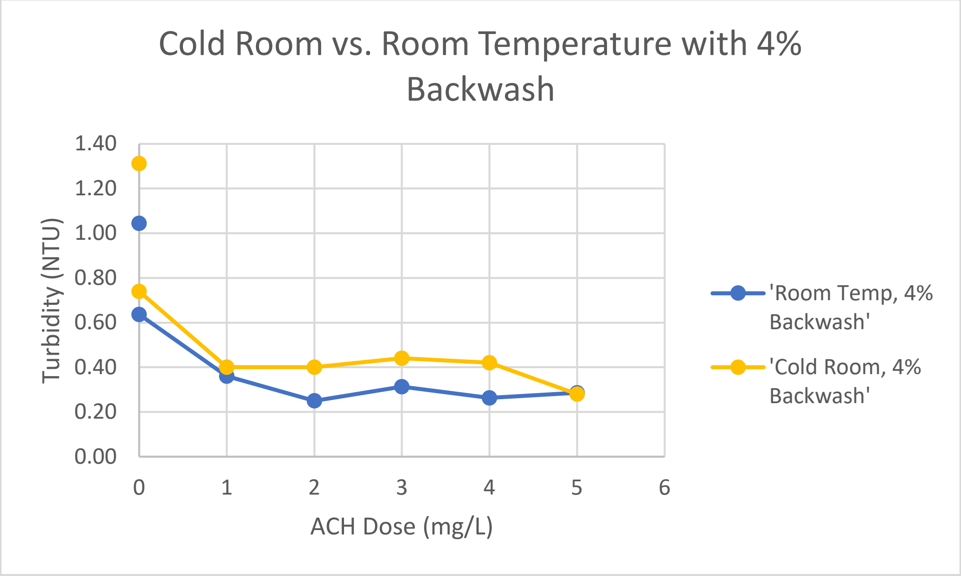

Figure 6: Cold Room vs. Room Temperature with 4% Backwash

This figure compares 4-hour settling turbidity measurements of the cold and room temperature with 4% backwash. The initial turbidities are displayed as separate points for each temperature.

The colder temperature also slows the reaction rate as there is less kinetic energy in the system. As a result, the cold room treatments settle at a slower rate than in the room temperature treatments. There seems to be little difference in the trend when comparing backwash and non-backwash containing samples.

If current coagulant dosage addition is based upon room temperature tests, then the coagulant addition could be further optimized by testing water at actual inlet temperature conditions. If this is not possible with current resources, keeping samples at a constant temperature by using a mini fridge for the samples after coagulant addition and rapid mixing during the jar tests, or acclimating the samples to room temperature prior to mixing could reduce this variability.

Backwash Addition

Since one goal of adding backwash water was to increase the turbidity of the influent water in the jar testing it was expected that the jars containing 4% backwash would have higher influent turbidities. The results of the jar test trials, shown in Figure 7 and Figure 8 indicate that at certain ACH dosages, the final turbidities after a 4-hour settling period are roughly the same between backwash and non-backwash-containing jars, without considering the influent turbidity of the sample used.

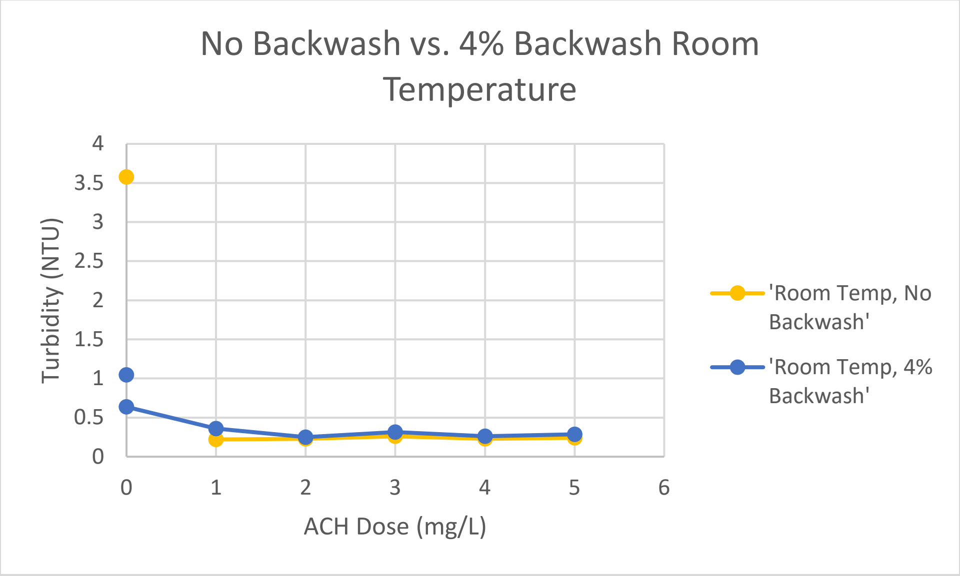

Figure 7: Backwash vs. No Backwash at Room Temperature

This figure contains the room temperature 4-hour settling turbidity data for both the 4% backwash treatments and non-backwash-containing treatments. The initial turbidities are displayed as separate points for each backwash condition.

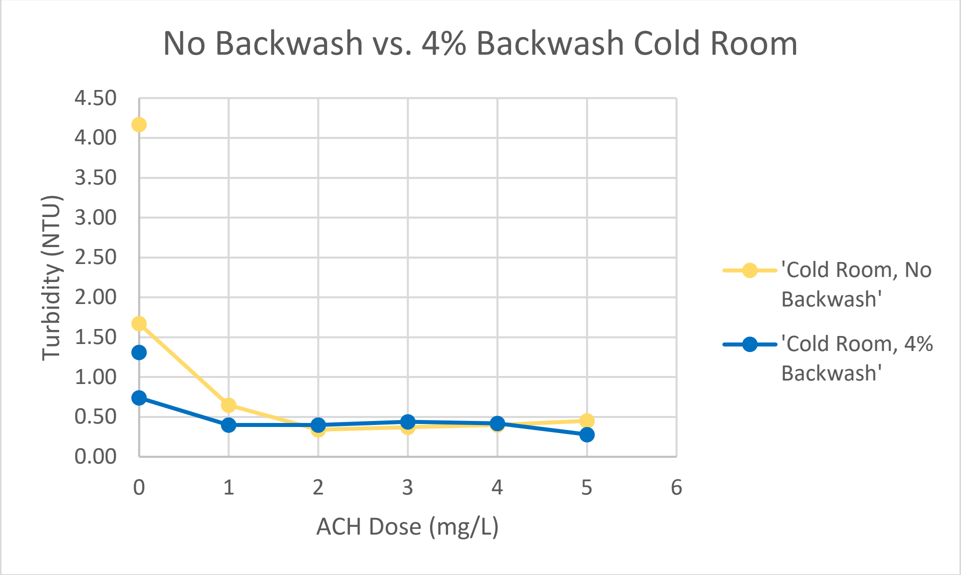

Figure 8: Backwash vs. No Backwash in the Cold Room

This figure contains the cold room 4-hour settling turbidity data for both the 4% backwash treatments and non-backwash-containing treatments. The initial turbidities are displayed as separate points for each backwash condition.

In considering the initial turbidity for each condition, it is important to note that the marked initial turbidity of the water was recorded without the addition of backwash, and the influent turbidities between the backwash and no backwash containing samples would likely be much closer when the addition of backwash is considered in the influent turbidity. The very small difference in effluent turbidity with likely similar influent turbidities indicates that backwash addition performs similarly to higher turbidity water with no backwash addition. This means that raising the turbidity of influent water with backwash would not affect the effluent turbidity of the pretreatment process with the current ACH dosing procedure. The addition of backwash could, however, increase the amount of ACH used in the process.

Sludge Settling

The pass/fail results for the 50% settling requirement and average settling depth of the sludge settling tests are displayed in Table 3. All tests with a polymer concentration greater than four milligrams per liter passed the four-minute settling depth parameters. The most compact sludge cake with the highest degree of settling after one hour is shown to be the polymer dose of five milligrams per liter. Sludge cakes with different degrees of compaction are shown in Figure 9. For each test, the most compact sludge cake was observed and marked with an X.

Table 3: Sludge Settling Results

Polymer Concentration (mg/L)	**Frequency of Pass**	**Pass Fail Based on Average**	**Average volume 4 minute Settling (mL)**	**Average volume 60 minute Settling (mL)**	**Most Compact Sludge Cake**
0	0%	Fail	923	304	
1	0%	Fail	730	280	
2	40%	Pass	382		
3	50%	Pass	500	265	XX
4	50%	Fail	440	265	
5	100%	Pass	336	229	XXXX
6	100%	Pass	373	258	XXX
7	100%	Pass	320	290	
8	100%	Pass	225	283	
9	100%	Pass	345	305	
10	100%	Pass	253	238	
15	100%	Pass	250	275	
20	100%	Pass	270	288	

The raw data displayed was collected during the student testing in the fall of 2021. The most compact sludge cake was determined from a vote in each lab testing period for the most compact sludge cake of the ones that had passed the 50% settling requirement.

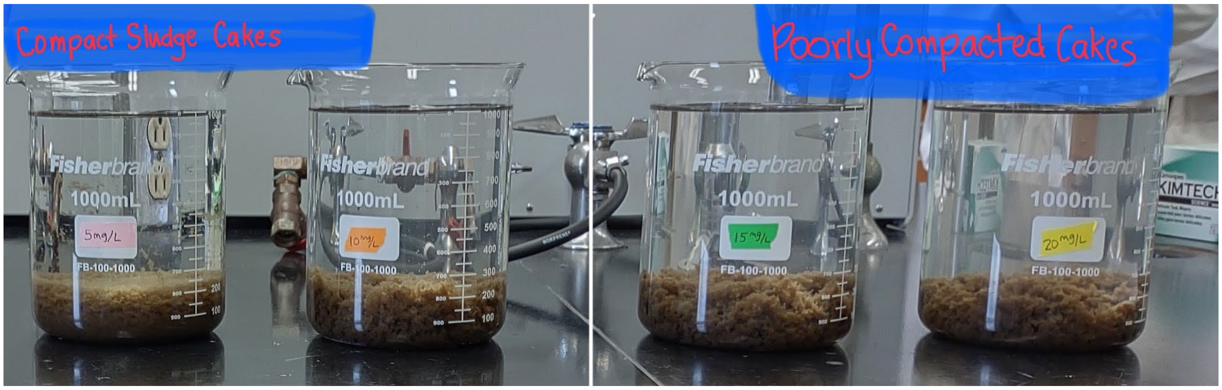

Figure 9: Compacted Sludge Poorly Compacted Cakes

The frequency of pass described in Table 3 is representative of the percent of lab groups that passed the settling requirement with the specified polymer dose, while the pass/fail based on average is a single rating based on the average settled volume for a given polymer dose. The average volumes represent the average settled volumes for all tests at a given polymer dose. Five mg/L of polymer addition to the wastewater resulted in the most compact sludge cake, while passing the 50% settling condition 100% of the time. This is recommended as the optimal dose for the wastewater that was tested.

Final Recommendations

The data collected does not indicate that the Bozeman WTP should deviate from current ACH dosing methods using the 1:1 ratio and multiplier method. In the case of jar testing, it is recommended that the Bozeman WTP test the water at a constant temperature, preferably at the current influent temperature to reduce variability and obtain accurate results for the conditions. If tests cannot be performed at influent temperature, it is recommended that a constant temperature be used. Samples could be placed in a mini fridge at the influent temperature after mixing to allow settling to occur at influent temperature (around 40̂ F), or the sample could be acclimated to room temperature prior to testing, although this method's variability and accuracy has not been tested. In addition, it is recommended that jar testing at the Bozeman WTP be performed over 4-hour settling periods to encapsulate the actual settling conditions in the sedimentation basin.

The addition of 4% backwash to the pretreatment process did not significantly impact the effluent turbidity as compared to jars without the addition of 4% backwash addition, at four hours of settling time. This comparison was made between samples with backwash whose initial turbidity was similar to those without backwash. The addition of backwash will likely raise the influent turbidity, and with a subsequent adjustment of the ACH dose in accordance with current procedures, the turbidity exiting the pretreatment process to the membrane filters would not be affected. While this process would use more ACH to treat the higher influent turbidity, it would greatly reduce the stress on the drying beds and would effectively recycle the otherwise wasted water.

Student testing found that a polymer dose of 5 mg/L yielded the most compact sludge cake for the water samples tested and met WTP requirements regarding 50% settling in four minutes. It is recommended that the Bozeman WTP use a polymer dose of 5 mg/L for gravity sludge thickener influent turbidities similar to those recorded in October 2021. This is concurrent with the data that was provided by the Bozeman WTP in 2021 on their current dosing.

In the future, it is recommended that testing be done to examine the effect that the addition of backwash has on ACH dose at varying influent turbidites and throughout different seasons. It is also recommended that different backwash concentrations be tested to determine the impact on the pretreatment process from raising the concentration. This testing could be performed in a similar collaboration as this project with MSU students.

References

WIOA. (Retrieved November, 2021). *An Operator's Guide to Water Treatment Coagulents.*

Appendix

Table 4: Raw Data Collected for Additional Tests

Key:		
	☐	= data point
	🟩	= acceptable variance
	🟧	= high variance
	🟨	= 4 hour turbidity higher than 45 minute

Water Sample 1

Date, Room Temp.	**Trial #**	**Initial Turbidity (NTU)**	**Backwash Concentration**	**ACH Concentration (mg/L)**	**Turbidity at 45 min (NTU)**	**Turbidity at 4 hours (NTU)**
2/8/2022, 70F	1	4.68	0%	0	1.22	0.89
	2	4.81	0%	0	0.99	0.96
	3	4.43	0%	0	0.97	0.97
	Average	4.64		0	1.06	0.94
	St. Dev.	0.16			0.113	0.036
	COV (%)	3.40%			10.70%	3.79%
	4	4.68	0%	1	0.65	0.32
	5	4.81	0%	1	0.70	0.38
	6	4.43	0%	1	0.14	0.37
	Average	4.64		1	0.50	0.36
	St. Dev.	0.16			0.253	0.026
	COV	3.40%			50.94%	7.36%

Date, Room Temp.	**Trial #**	**Initial Turbidity (NTU)**	**Backwash Concentration**	**ACH Concentration (mg/L)**	**Turbidity at 45 min (NTU)**	**Turbidity at 4 hours (NTU)**
2/10/2022, 45F	1	2.61	0%	0	1.63	0.97
	2	2.53	0%	0	1.72	0.97
	3	2.82	0%	0	1.62	0.99
	Avg.	2.65		0	1.66	0.98
	St. Dev.	0.12			0.045	0.009
	COV	4.61%			2.71%	0.97%
	4	2.89	0%	1	1.65	0.47
	5	2.73	0%	1	1.37	0.46
	6	2.7	0%	1	1.35	0.29
	Average	2.773		1	1.46	0.41
	St. Dev.	0.08			0.137	0.083
	COV	3.01%			9.40%	20.31%

Date, Room Temp.	Trial #	Initial Turbidity (NTU)	Backwash Concentration	ACH Concentration (mg/L)	Turbidity at 45 min (NTU)	Turbidity at 4 hours (NTU)
2/15/2022, 70F	RO Water	0.06	0%	0	0.09	0.08
	1	4.09	0%	1	0.17	0.22
	2	3.58	0%	2	0.20	0.23
	3	4.02	0%	3	0.09	0.26
	4	4.19	0%	4	0.25	0.23
	5	2.01	0%	5	0.27	0.24
	Average	3.58			0.20	0.24
	St. Dev.	0.81			0.064	0.014
	COV	22.67%			32.53%	5.75%

Water Sample 2

Date, Room Temp.	Trial #	Initial Turbidity (NTU)	Backwash Concentration	ACH Concentration (mg/L)	Turbidity at 45 min (NTU)	Avg. Turbidity at 4 hours (NTU)
2/22/2022, 70 F	Blank (no BW)	0.65	0%	0	n/a	n/a
	0	1.13	4%	0	0.78	0.64
	1	1.11	4%	1	0.16	0.36
	2	0.91	4%	2	0.17	0.25
	3	0.94	4%	3	0.13	0.31
	4	1.00	4%	4	0.16	0.26
	5	1.18	4%	5	0.20	0.29
	Average	1.05			0.27	0.35
	St. Dev.	0.10			0.23	0.13
	COV	9.64%			86.43%	37.64%

Date, Room Temp.	Trial #	Initial Turbidity (NTU)	Backwash Concentration	ACH Concentration (mg/L)	Turbidity at 45 min (NTU)	Avg. Turbidity at 4 hours (NTU)
3/2/2022, 40 F	0	1.37	4%	0	1.09	0.74
	1	1.28	4%	1	1.24	0.40
	2	1.34	4%	2	1.21	0.40
	3	1.25	4%	3	1.17	0.44
	4	1.24	4%	4	1.20	0.42
	5	1.39	4%	5	1.45	0.28
	Average	1.31			1.23	0.45
	St. Dev.	0.06			0.110	0.141
	COV	4.43%			8.99%	31.52%

Water Sample 3

Date, Room Temp.	Trial #	Initial Turbidity (NTU)	Backwash Concentration	ACH Concentration (mg/L)	Turbidity at 45 min (NTU)	Avg. Turbidity at 4 hours (NTU)
3/10/22, 40F	0	3.68	0%	0	3.14	1.67
	1	4.14	0%	1	2.79	0.65
	2	3.67	0%	2	2.58	0.34
	3	4.63	0%	3	2.84	0.37
	4	4.83	0%	4	2.86	0.40
	5	4.06	0%	5	2.99	0.45
	Average	4.17			2.87	0.65
	St. Dev.	0.44			0.173	0.469
	COV	10.50%			6.02%	72.46%

The raw data displayed was collected for three water samples. The cell colors can be interpreted using the key, with a high COV desired for the 0-5 mg/L testing to allow for accurate pinpointing of the optimal ACH dose, and a low COV desired for the triplicate testing, to allow for precise test results and low testing variability.

Table 5: Student ACH Dose Testing

Jar Testing Data 10/19 Cold Room at 40 degrees F

ACH Concentration (mg/L)	Backwash	Turbidity (Avg.) (NTU)	Range
0	Initial	1.41	0.27
0	None	0.89	0.01
1	None	1.08	0.42
2	None	1.07	0.04
3	None	1.29	0.24
4	None	1.27	0.16
5	None	1.34	0.16
0	4%	1.45	0.04
1	4%	1.58	0.01
2	4%	1.63	0.05
3	4%	1.75	0.16
4	4%	1.69	0.18
5	4%	1.95	0.26

Jar Testing Data 10/26 Room Temperature

ACH Concentration (mg/L)	Backwash	Turbidity (Avg.) (NTU)	Range
0	Initial	1.29	0.13
0	None	0.59	0.17
1	None	0.68	0.08
2	None	0.89	0.08
3	None	0.71	0.16
4	None	0.80	0.10
5	None	0.89	0.24
0	4%	0.97	0.29
1	4%	1.16	0.12
2	4%	1.16	0.24
3	4%	1.19	0.36
4	4%	1.15	0.07
5	4%	0.90	0.08

Jar Testing Data 11/2 Cold Room (40 degrees F)				
ACH Concentration (mg/L)	**Backwash**	**Turbidity (Avg.) (NTU)**	**Turbidity (St. Dev.)**	**COV (%)**
0	Initial	6.09	1.60	
10	None	1.59	0.44	27.45%
15	None	1.59	0.64	40.44%
20	None	2.28	0.71	31.07%
10	4%	2.40	1.84	76.60%
15	4%	1.46	0.53	36.07%
20	4%	2.00	0.46	22.95%

The raw data displayed was collected during student testing in the fall of 2021. The cell colors can be interpreted using the key. The range is color coded with low ranges being green and high ranges being red. For the high turbidity testing, the darker red the color, the higher the COV above the threshold value of 10%, and the darker green the color, the lower the COV below the threshold value.

Table 6: Student Sludge Compaction Testing

Polymer Concentration (mg/L)	**Pass/ Fail (average)**	**Frequency of Pass**	**Pass Fail Based on Average**	**Average 4-minute Settling (mg/L)**	**Average 60-minute Settling (mg/L)**	**Most Compact Sludge Cake**
0	Fail	0.00%	Fail	923.3333333	303.75	
1	Fail	0.00%	Fail	730	280	
2	Fail	40.00%	Pass	382		
3	None	50.00%	Pass	500	265	XX
4	None	50.00%	Fail	440	265	
5	Pass	100.00%	Pass	336.25	229.375	XXXX
6	Pass	100.00%	Pass	372.50	257.50	XXX
7	Pass	100.00%	Pass	320.00	290.00	
8	Pass	100.00%	Pass	225	282.5	
9	Pass	100.00%	Pass	345	305	
10	Pass	100.00%	Pass	252.5	238.3	
15	Pass	100.00%	Pass	250	275	
20	Pass	100.00%	Pass	270	287.5	

The raw data displayed was collected during the student testing in the fall of 2021. The most compact sludge cake was determined from a vote in each lab testing period for the most compact sludge cake of the ones that had passed the 50% settling requirement.