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Water Resources Series No. 41

THE EFFECTIVENESS OF SAND FILTERS FOR THE
REMOVAL OF COLLOIDAL MANGANESE OXIDES
FROM WATER USING SELECTED
CATIONS AS FILTER AIDS

January 31, 1974

A Project Completion Report of a Study of B-011-WYO

Research on which this report is based was funded in part through the Wyoming Water Resources Research Institute by the Office of Water Resources Research, Department of the Interior under the Water Resources Research Act of 1964.

Project Title: The Effectiveness of Sand Filters for the Removal of Colloidal Manganese Oxides from Water Using Selected Cations as Filter Aids.

OWRR Project Number: B-011-WYO

Agreement Number: 14-31-0001-3950

Project Investigator: Stephen R. Jenkins

Investigator's Institution: University of Wyoming

Period Covered by Investigation: July 1, 1972 to January 31, 1974

The Project Objectives were:

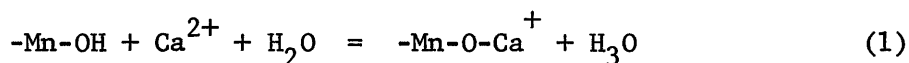
- 1) To extend a mathematical model developed for a rotating disc surface to predict the removal of manganese oxides in actual sand filters.
- 2) To project the cost of effective manganese removal in water treatment facilities by addition of selected cations.

ACCOMPLISHMENT OF OBJECTIVE I

TO EXTEND A MATHEMATICAL MODEL DEVELOPED FOR A ROTATING DISC SURFACE TO PREDICT THE REMOVAL OF MANGANESE OXIDES IN ACTUAL SAND FILTERS.

In the present study, the mathematical-chemical formulation for predicting the removal of manganese oxides on a rotating disc surface was shown to also predict the removal efficiency of actual model sand filters for manganese oxides.

Using a rotating disc surface, it has been shown (1,2) that calcium ions can associate with the surface sites of manganese oxide to lower the negative surface charge. That is:



where -Mn- stands for a manganese central ion and -Mn-OH stands for hydrated surface groups. A stability constant K_s , was determined for this reaction and found to be:

$$K_s = \frac{[-MnO-Ca^+][H^+]}{[-Mn-OH][Ca^{2+}]} = 10^{-5.5} \quad (2)$$

Using this stability constant and the condition:

$$[-Mn-O-Ca^+] = 0.35 [-Mn-O^-] \quad (3)$$

determined by experimentation, previous research has shown, that the concentration of Ca^{2+} necessary to cause maximum deposition of manganese oxide on a rotating disc is predictable if the concentration of manganese oxide is known.

In the present study the model sand filters (Figure 1) used were one-inch plexiglass tubes filled to a depth of four inches with Ottawa

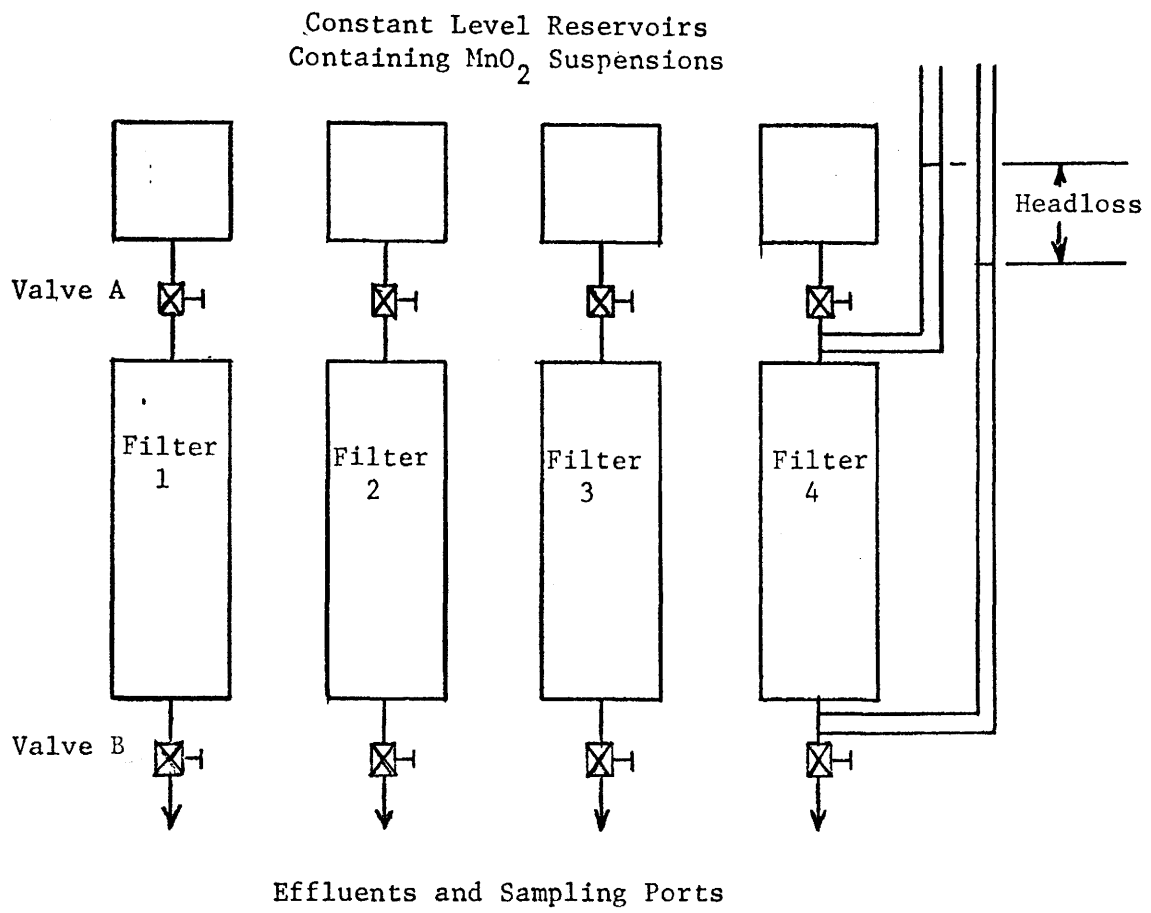


Figure 1. Schematic of Sand Filter Apparatus.

Sand. These filters were equipped with manometers which were used to measure the total headloss across each of the filters. The sand was added to the plexiglass tubes and soaked with water overnight before each use. The rate of filtration was set at 2 gpm/ft^2 in accordance with current practice for operation of rapid sand filters. This flow rate was maintained throughout each filter run by adjustment of valve B which is shown in Figure 1.

EXPERIMENTAL PROCEDURES

The stock $4 \times 10^{-3} \text{ M}$ " $\delta\text{-MnO}_2$ " solutions were prepared well in advance of their use by stoichiometric additions of Mn^{2+} and MnO_4^- as explained by Jenkins (1). Before each filter run this stock manganese oxide solution was diluted to the desired concentration. While vigorous stirring conditions were maintained, the ionic strength, Ca^{2+} concentration, and pH were adjusted to the desired levels. Ionic Strength (I) was maintained at the desired level with additions of 10^{-1} M NaNO_3 . Calcium and pH levels were adjusted by additions of $10^{-2} \text{ M Ca(NO}_3)_2$ and 10^{-1} M NaOH , respectively. These solutions were stirred slowly (100 rpm) for 20 minutes. The filter run was then begun. The manganese oxide solutions were passed through the filters at a constant rate of 2 gpm/ft^2 as stated above for 45 minutes. During the filter run the oxide solution was stirred continuously at a low rate to prevent sedimentation of any aggregate particles. The amount of " $\delta\text{-MnO}_2$ " passing the filter was determined as a function of time using the o-tolodene procedure of Morgan and Stumm (3). After each 45 minute filter run, the manganese oxide solution was removed and distilled water was passed through the filter for 15 minutes. During the filter runs, each time a sample of the filter effluent was taken, the headloss across the filter was determined.

At the termination of each filter run, the sand was removed from the plexiglass tube. The amount of " δ -MnO₂" adhering to the sand was determined by washing the sand with distilled water and measuring with o-tolodene the manganese oxide contained in the wash water.

RESULTS

The percent amount of " δ -MnO₂" remaining in the effluent can be calculated from the o-tolodene measurement of the concentration of the oxide passing the filter and a knowledge of the influent concentration of " δ -MnO₂". A plot of percent MnO₂ remaining the the effluent versus time can then be made. (Figure 2)

For very small doses of Ca²⁺ (1.55×10^{-4}) little appreciable increase in filter effectiveness was noted. However, with subsequent increases in Ca²⁺, a dramatic increase in filter effectiveness was noted until a maximum effectiveness (a minimum percent MnO₂ remaining in effluent) was reached. The first concentrations of Ca²⁺ necessary to produce the maximum effectiveness is termed the maximum effectiveness concentration (mec) of the filter aid. Although concentrations of Ca²⁺ greater than the mec (2.3×10^{-4} M for a $[\text{MnO}_2] = 2.65 \times 10^{-3}$ M (Figure 2)) may increase the removal slightly, the increase was minimal. Also, at these mec of Ca²⁺, the headloss became so large that it was impossible to maintain a constant flow rate of 2 gpm/ft² (Figure 3).

An increase in headloss during filtration indicated an effectiveness of the filter for particle removal. Figure 3 indicates that with increasing concentrations of Ca²⁺ in the " δ -MnO₂" solutions, the headloss increases faster than with lesser concentrations of Ca²⁺, thus indicating a better removal effectiveness. The minimum concentration of Ca²⁺ necessary to

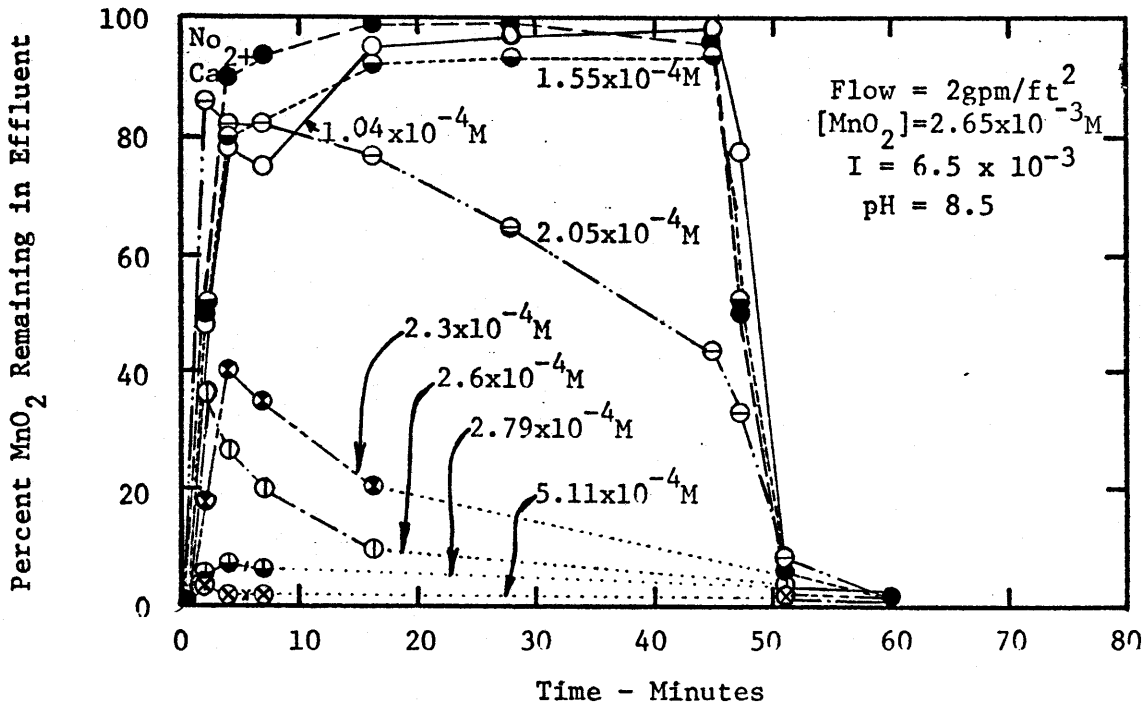


Figure 2. The Percent of MnO₂ Which Remains in the Effluent Versus Time. The filter run was terminated after forty-five minutes and distilled water was passed through the filter. Total calcium concentrations are shown. Similar curves were obtained at pH 6.5 and other MnO₂ concentrations.

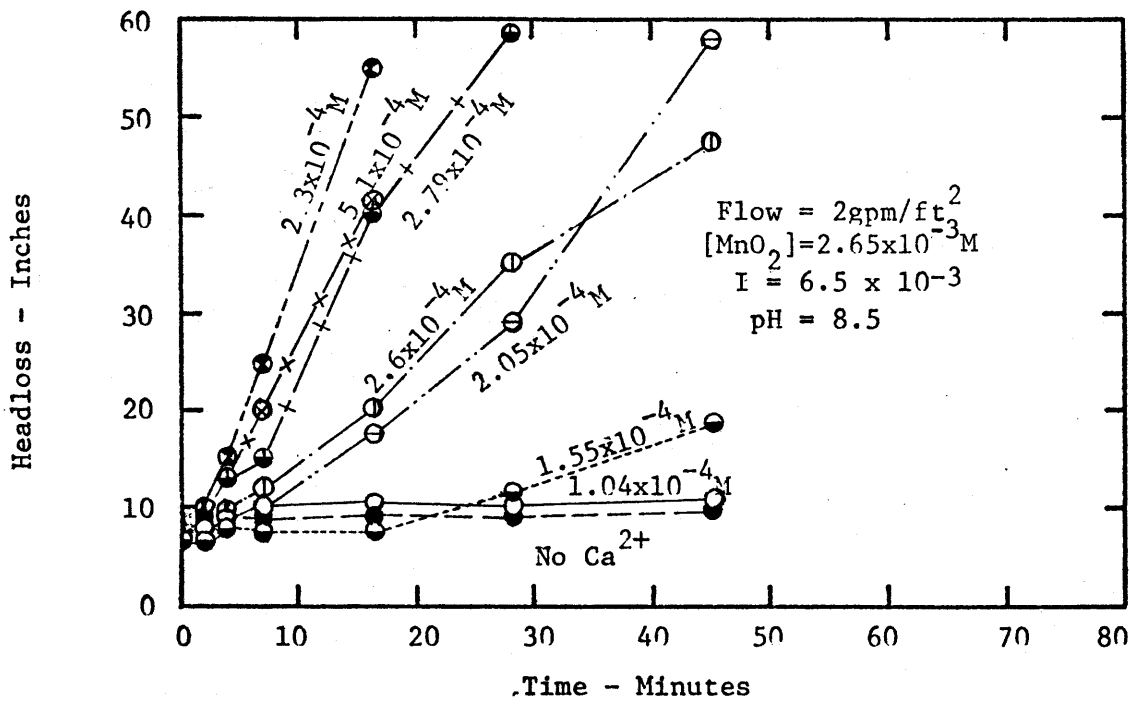


Figure 3. The Headloss Across the Filters Versus Time. Typical data.

produce the maximum filter effectiveness (mec) from Figure 6 is the same $[Ca^{2+}]$ necessary to produce the maximum rate of headloss build-up. For a concentration of " δ - MnO_2 " of 2.65×10^{-3} M at pH 8.5, the mec of Ca^{2+} is 2.3×10^{-4} M. The removal effectiveness was so great at this Ca^{2+} concentration that all 56 inches of available headloss was used in 16 minutes and the run had to be terminated prematurely. Similarly, all runs made with a " δ - MnO_2 " concentration of 2.65×10^{-3} M and a calcium concentration greater than 2.3×10^{-4} had to be terminated prematurely because of clogging.

In Figure 4, the total amount of MnO_2 adhering to the 4-inch column of sand is plotted versus the concentration of Ca^{2+} . It can be seen from this plot that the effectiveness of the filter for removal of MnO_2 is substantially higher when the concentration of Ca^{2+} is about 2.3×10^{-4} . The filled circles (●) in Figure 4 represent the amount of MnO_2 adhering to the sand as determined by direct measurement with the o-tolodene method. The open circles (○) represent the amount of oxide unaccounted for by taking the difference of the influent and effluent concentrations of MnO_2 over the period of the entire filter run. Little appreciable difference in these results can be seen, indicating that the percent MnO_2 in the effluent results are reliable. If the mec of Ca^{2+} is plotted versus each MnO_2 concentration, a stoichiometric relationship results (Figure 5).

The mec of Ca^{2+} for removal of " δ - MnO_2 " by these model sand filters are similar to the critical coagulation concentrations and the maximum adhesion concentrations for coagulation and adherence of " δ - MnO_2 " particles to silica surfaces (1). Therefore, the mathematical-chemical model

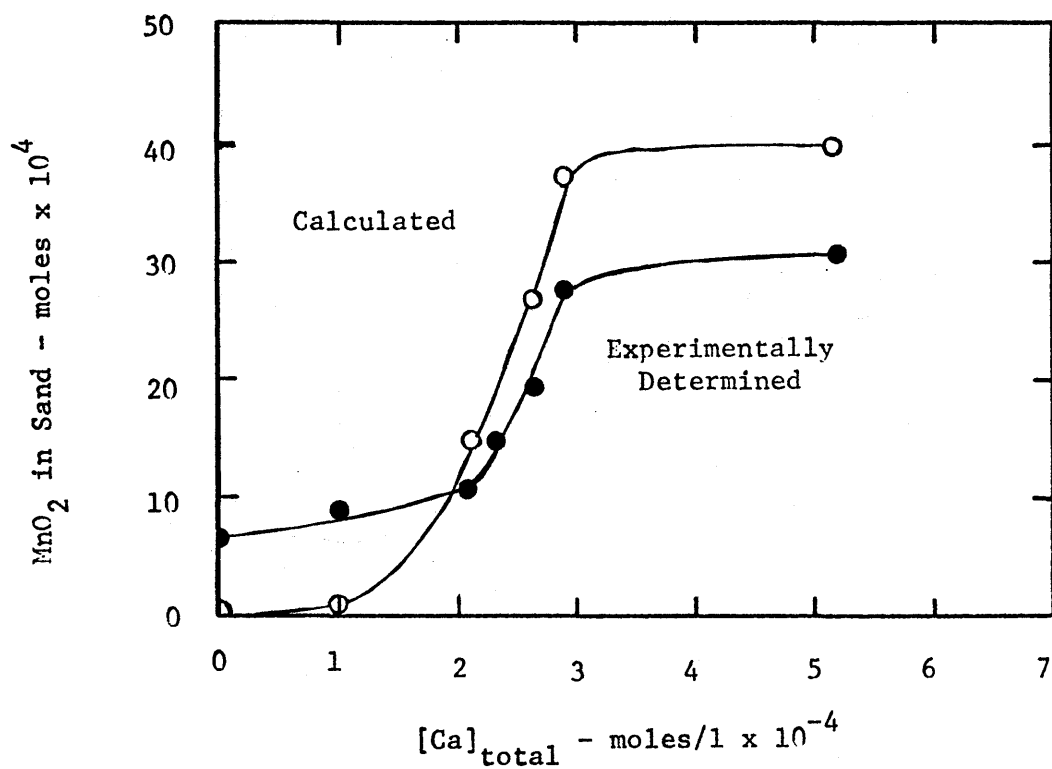


Figure 4. The Total Amount of MnO₂ Adhering to the Sand Versus the Total Calcium Concentration. Data shown is for [MnO₂] = 2.65 × 10⁻³, pH 8.5 and I = 6.5 × 10⁻³. Typical data.

determined for predicting the concentrations of Ca^{2+} necessary to cause removal of each concentration of " $\delta\text{-MnO}_2$ " by coagulation or adhesion can be used to predict the mec of Ca^{2+} by rapid sand filters. That is, using the condition:

$$[-\text{Mn-O-Ca}^+] = 0.35 [-\text{Mn-O}^-] \quad (7)$$

for each mec of Ca^{2+} , the total amount of Ca^{2+} needed can be determined as described by Stumm et al (2) and Jenkins (1).

Effect of pH

The influence of pH on the effectiveness of the filter to remove " $\delta\text{-MnO}_2$ " is minimal (Figure 5). This is in agreement with the earlier findings of Jenkins (1). At higher oxide concentrations, the mec dose of Ca^{2+} increases slightly with increasing pH.

Effect of Precoating

Precoating the sand filters with Ca^{2+} has a detrimental effect. If the filter is soaked overnight with a solution containing the same concentration of Ca^{2+} as the MnO_2 solution to be filtered, a decrease in efficiency of the filter to remove " $\delta\text{-MnO}_2$ " results (Figure 6). It is believed that Ca^{2+} also reacts with the $-\text{Si-OH}$ surface sites of the sand during filtration. The Ca^{2+} can thus act as a bridge between the " $\delta\text{-MnO}_2$ " and the sand surface during filtration. By precoating the filter with Ca^{2+} , the surface sites available to $-\text{Mn-O-Ca}^+$ will be occupied before filtration begins. As " $\delta\text{-MnO}_2$ " is passed through the filter, the filter efficiency is reduced because there are fewer available $-\text{Si-OH}$ sites for the $-\text{Mn-O-Ca}^+$ complexes to bridge.

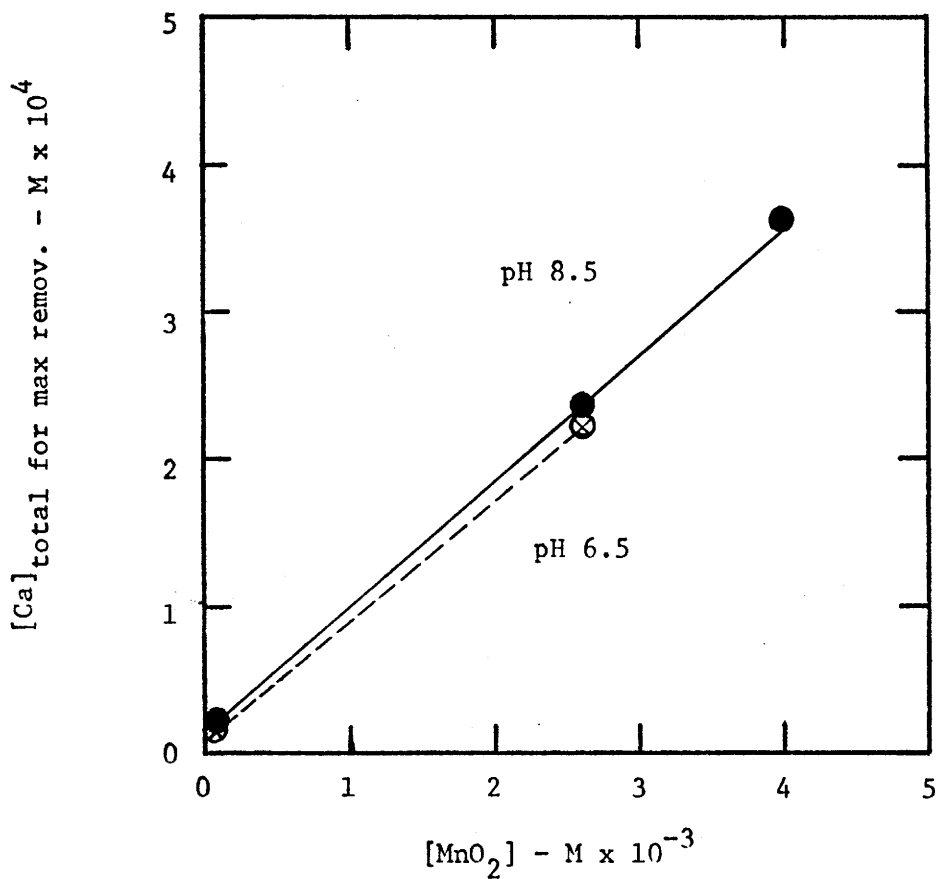


Figure 5. Stoichiometric Relationship Between the Concentration of Calcium Necessary to Produce a Maximum Filter Effectiveness (mec) of Model Sand Filters for Removal of " δ -MnO₂" and the Concentration of " δ -MnO₂" as a Function of pH. $I = 6.5 \times 10^{-3}$ and the flowrate is 2 gpm/ft².

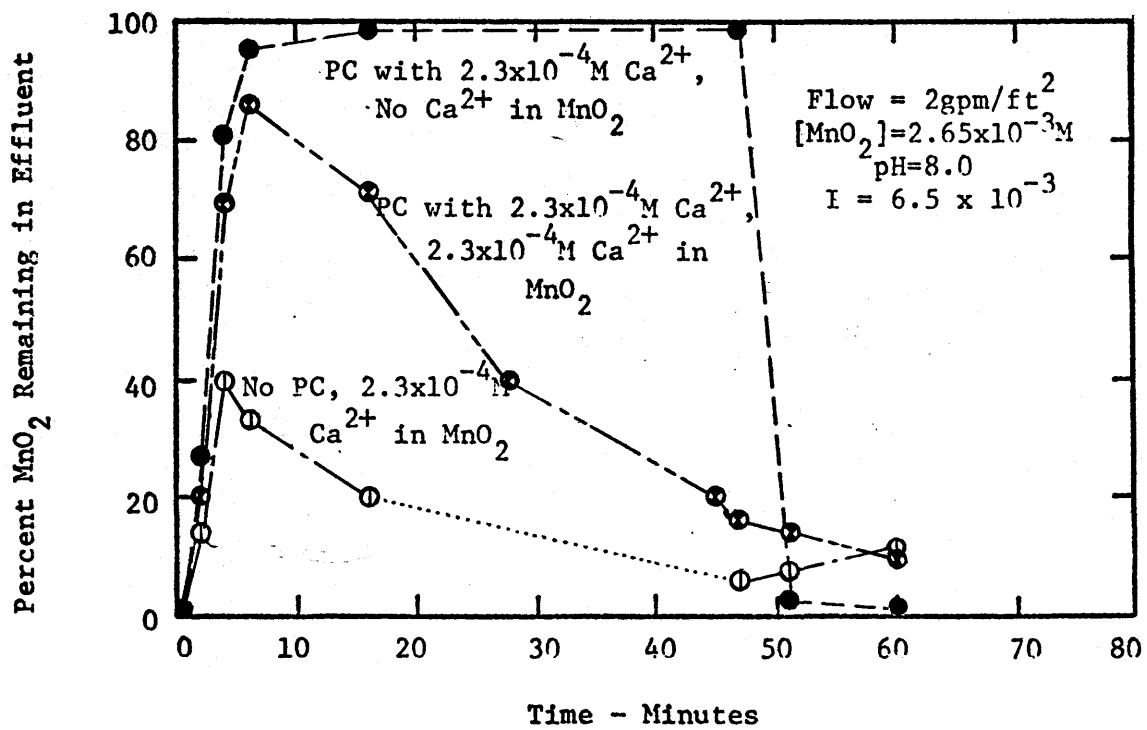


Figure 6. The Percent of MnO₂ which Remains in the Effluent Versus Time. PC indicates that the sand was soaked overnight with the indicated [Ca²⁺].

Effect of Filtration Rate

A four-fold increase in flow rate (2 gpm/ft² to 8 gpm/ft²) results in the mec of Ca²⁺ increasing slightly (Figure 7). This is in agreement with Yao, et al (4) who showed that latex particles were more easily removed by low rates of filtration. That is, the mec of Ca²⁺ should go up as the rate of filtration goes up. This data also supports the theory of O'Melia and Stumm (5) who indicate that both chemical and physical phenomena must be considered when studying filtration.

Effect of Cation Selection

If Na⁺ is used instead of Ca²⁺ as the filter aid, the mec (Figure 8) of Na⁺ agrees well with values reported by others (e.g. Tezak (6)) for aggregation of hydrophobic colloids. This aggregation is promoted by double-layer compaction rather than specific chemical interaction. Furthermore, because of the lack of specific chemical interaction between this cation and the surface of "δ-MnO₂", no stoichiometric relationship exists between mec of Na⁺ and the [MnO₂] (Figure 9). Similar results were reported by Jenkins (1) for the aggregation and deposit study discussed previously.

CONCLUSIONS AND SUMMARY

The concentration of Ca²⁺ necessary to produce maximum removal effectiveness of "δ-MnO₂" particles by model sand filters has been shown to be stoichiometric with the concentration of "δ-MnO₂", thus indicating a specific chemical interaction between the Ca²⁺ and the "δ-MnO₂". These maximum effectiveness concentrations (mec) were similar to those concentrations of Ca²⁺ reported earlier necessary to produce both aggregation of "δ-MnO₂" and deposition of this oxide on

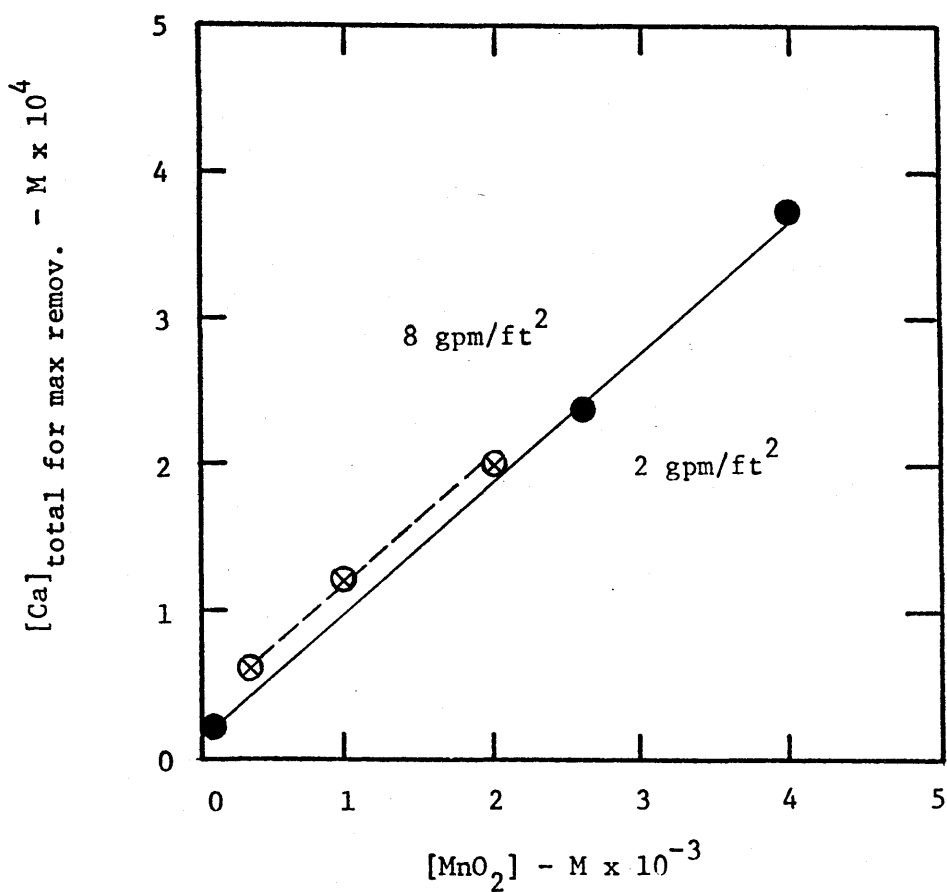


Figure 7. Stoichiometric Relationship Between the Concentration of Calcium Necessary to Produce a Maximum Filter Effectiveness (mec) of Model Sand Filters for Removal of " δ -MnO₂" and the Concentration of " δ -MnO₂" as a Function of Flowrate. $I = 6.5 \times 10^{-3}$ and pH 8.5.

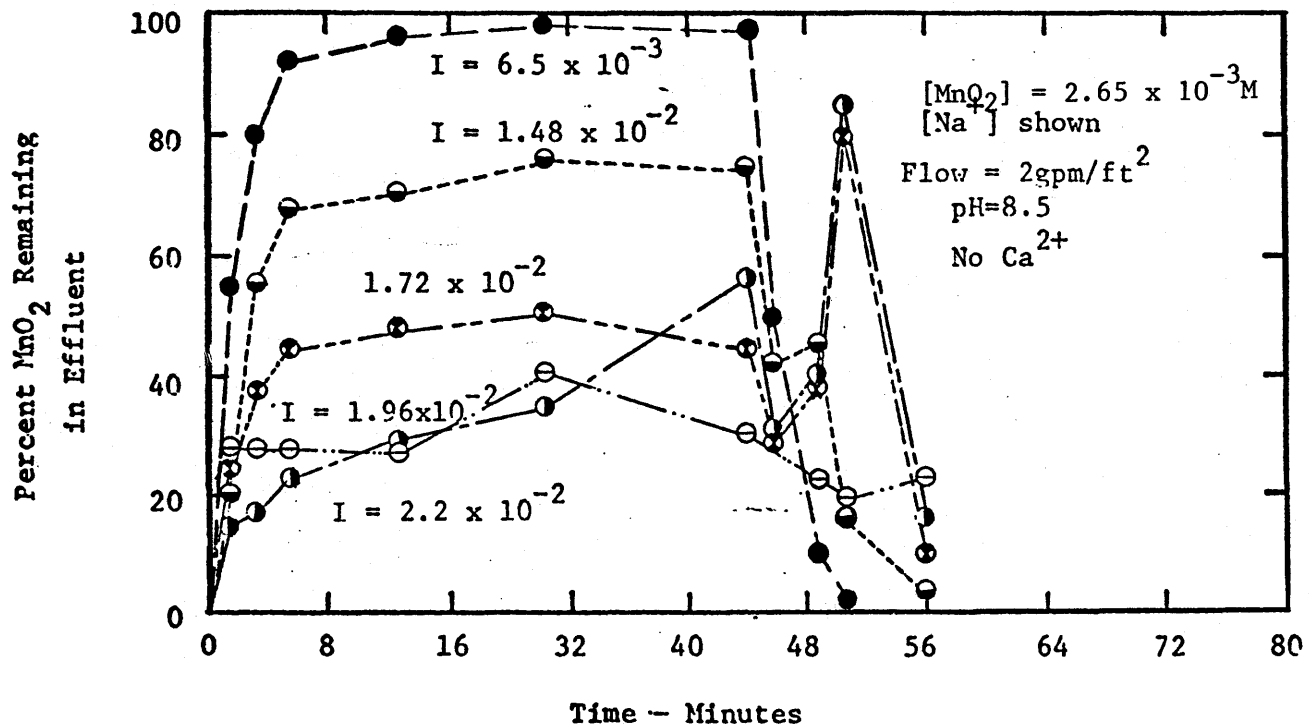


Figure 8. The Percent of MnO₂ Which Remains in the Effluent Versus Time When Sodium Ions (Na⁺) Is Used as the Filter Aid.

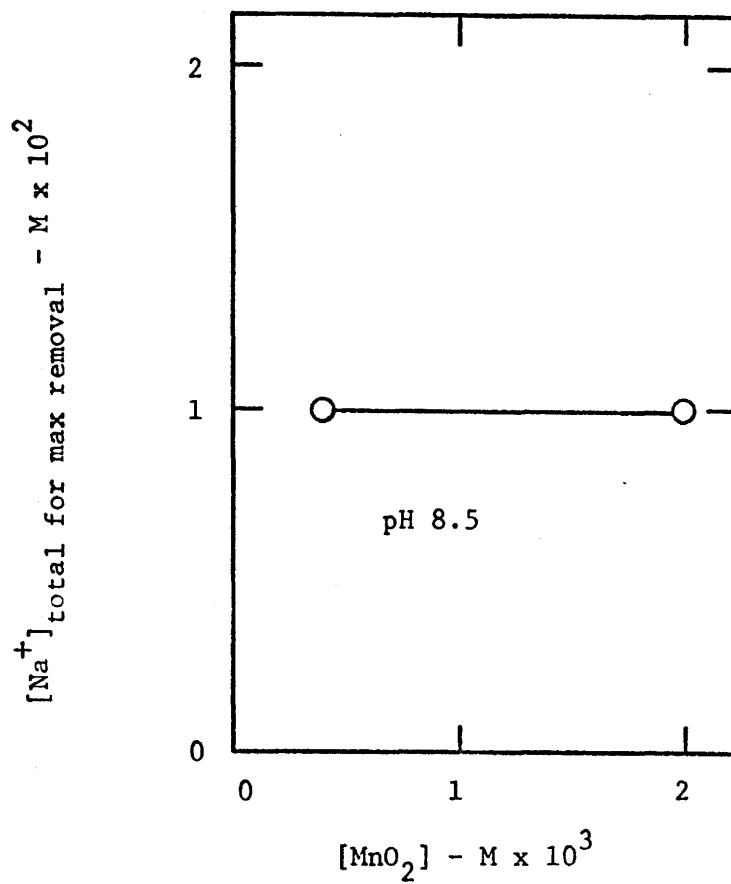


Figure 9. Stoichiometric Relationship Between the Concentration of Sodium Necessary to Produce a Maximum Filter Effectiveness (mec) of Model Sand Filters for Removal of " $\delta\text{-MnO}_2$ " and the Concentration of " $\delta\text{-MnO}_2$ ".

a rotating disc surface (1). The mathematical-chemical relationship, derived to predict the most effective concentrations of Ca^{2+} for coagulation of manganese oxide particles and deposition on silica surfaces, can be used to predict effective concentrations of Ca^{2+} for removal of " $\delta\text{-MnO}_2$ " by model sand filters.

Differences in pH, effect the mec of Ca^{2+} only slightly. However, precoating the sand with Ca^{2+} causes considerable change in the effectiveness of Ca^{2+} in aiding " $\delta\text{-MnO}_2$ " removal. It is most likely that the Ca^{2+} reacts with the negative -Si-O^- surface sites reducing the number of sites available for a bonding with the -Mn-O-Ca^+ surface sites.

If Na^+ is used as a filter aid instead of Ca^{2+} , the mec required indicates that Na^+ compresses the diffuse part of the double layer. No stoichiometry exists between the mec of Na^+ and the " $\delta\text{-MnO}_2$ " concentration. Thus, the destabilization of MnO_2 by Na^+ does not occur by a specific chemical interaction.

ACCOMPLISHMENT OF OBJECTIVE II

TO PROJECT THE COST OF EFFECTIVE MANGANESE REMOVAL IN WATER TREATMENT FACILITIES BY ADDITION OF SELECTED CATIONS.

THREE FOOT DEEP FILTERS

Using the information obtained under Objective I, a similar study was made using large sand filters to determine the feasibility of removing large amounts of manganese oxide with filters whose depths more normal depict actual practice. In this part of the study four-inch ID plexiglass tubes filled to a depth of three feet with Ottawa Sand were used. The manganese oxide suspensions, the experimental procedures and the analytical techniques used were as described for the four-inch deep sand filtration runs in the discussion of Objective I.

The results obtained from the large (3-foot deep) sand filters are essentially the same as those obtained for the small (4-inch deep) filters. Comparison of Figure 2 and Figure 10 indicate that the mathematical-chemical model used to predict the efficiency of the small sand filters for removal of " δ -MnO₂" as a function of Ca²⁺ concentration can also be used to predict the efficiency of the large filters. Figure 11 shows that the headloss build-up with the large filters are similar to that of the small ones (Figure 3).

ECONOMICS OF MANGANESE REMOVAL IN NATURALLY OCCURING WATERS OF WYOMING

Natural Occuring Manganese in Wyoming Water Supplies

Knowing the manganese oxide can be removed on a large scale basis with normal operation of rapid sand filters by additions of calcium ion to concentration which can be predicted, a study was made to determine the cost of using this technique on naturally occurring waters.

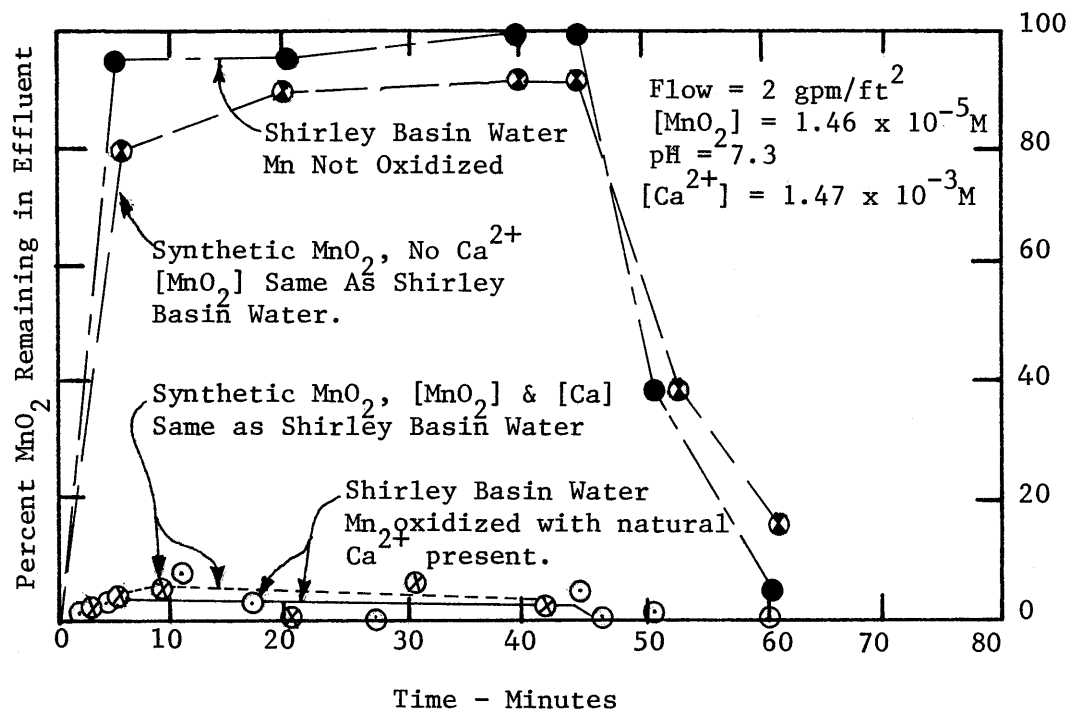


Figure 12. The Percent of MnO₂ which remains in the effluent versus time for Shirley Basin Water.

Few municipalities in Wyoming have naturally occurring manganese in their water supply. Those towns which do have natural manganese and the concentration of manganese are shown in Table 1. The manganese which does appear in Wyoming waters is in the Mn²⁺ state.

TABLE I
CITIES IN WYOMING WITH NATURALLY OCCURRING MANGANESE IN THEIR WATER SUPPLY.
As reported by the Water Quality Branch of the Wyoming Department of Environmental Quality (7).

City	1970 Population	Mn Concentration (mg/l)	Source of Water	Method of Treatment
Alpine Village	100*	0.14	Spring	None
Lovell	2,371	0.08	River	Softening, coagulation
Lusk	1,495	0.04	Well	None
Pinedale	948	0.35	Lakes	None
Rock River	344	0.1	River	None
Shirley Basin	200	0.4	Well	None
South Superior	400	0.2	Well	None
Sundance	1,056	0.07	Well	None
Torrington	4,237	0.04	Well	None

* Estimated population as exact number is not available.

Waters from Pinedale, Rock River, Shirley Basin and South Superior were obtained. The samples from Pinedale and Rock River had a manganese concentration of zero. The apparent discrepancy between this result and that reported by the Department of Environmental Quality most likely resulted from the samples being taken during different times of the year. These waters are supplied by surface sources which are very susceptible to seasonal changes.

The samples obtained for this study from Shirley Basin and South Superior had characteristics shown in Table II.

TABLE II
CHEMICAL CHARACTERISTICS OF NATURAL WATER SAMPLES OBTAINED FOR THIS STUDY.

City	[Mn] - mg/l	[Ca ²⁺] - mg/l	pH
Shirley Basin	0.48	59	7.3
South Superior	0.19	75	7.0

The manganese and calcium concentrations were measured by an atomic absorption technique. The pH was measured on site with a portable pH meter.

Removing Manganese From Natural Water With The Model Sand Filters.

To determine the feasibility of removing manganese from these naturally occurring waters by rapid sand filters using calcium as a filter aid, the manganese bearing waters were oxidized with MnO_4^- and were then passed through the four-inch deep sand filters using similar experimental techniques as discussed under Objective I.

The natural samples containing known concentrations of Mn^{2+} were placed in a vessel. Since the manganese is in the Mn^{2+} state, it must be oxidized first. Stoichiometric quantities of sodium permanganate were added to the samples to oxidize all of the Mn^{2+} to manganese oxide. These samples were stirred slowly for twenty minutes and then were passed through the filters at a rate of 2 gpm/ft². The amount of manganese oxide remaining in the effluent was determined and compared to the amount in the influent (Figure 12).

The results shown in Figure 12 are for the Shirley Basin water. However, similar results were obtained on the South Superior water.

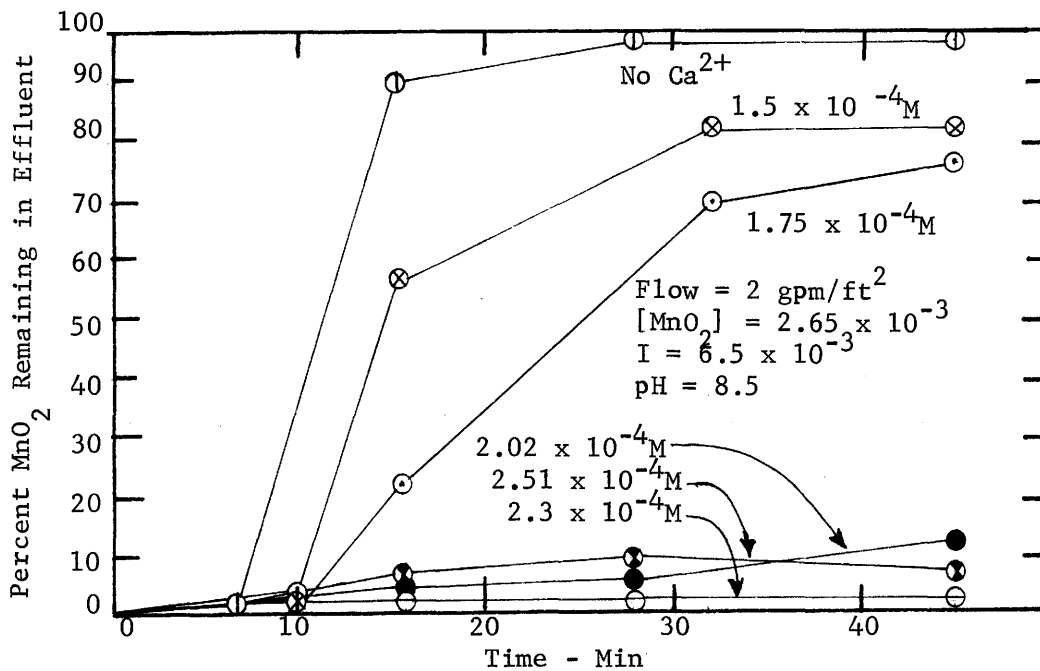


Figure 10. The Percent of MnO₂ Which Remains in the Effluent Versus Time for Three Foot² Deep Sand Filters. The filter run was terminated after forty-five minutes. Concentration of calcium is shown.

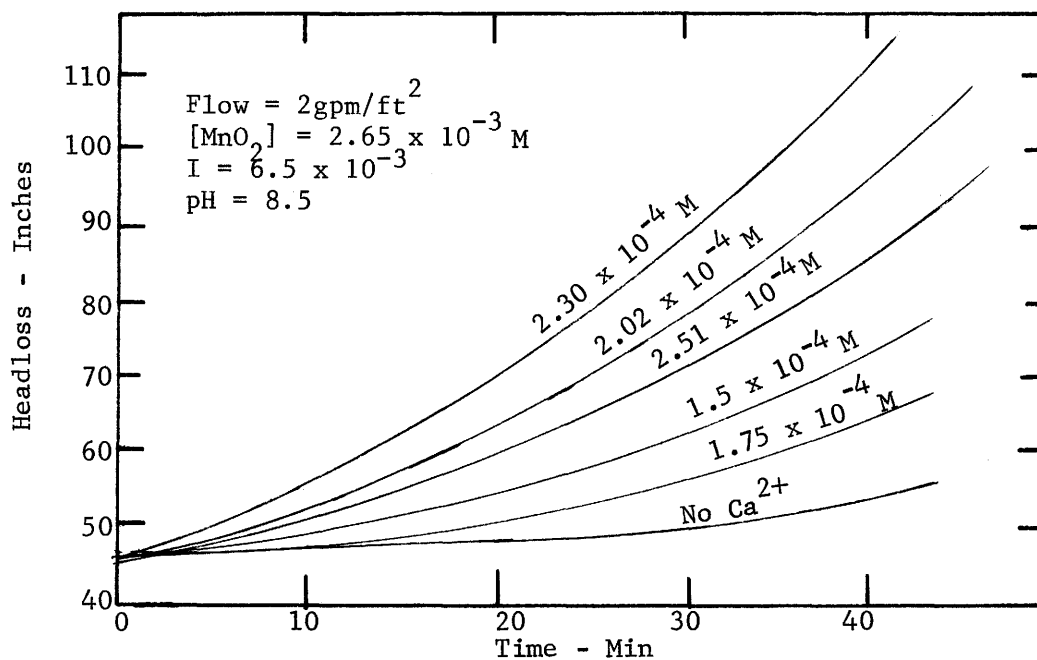


Figure 11. The Headloss Across the Three Foot Deep Sand Filter Versus Time. The headloss is only approximate as data was not taken on at regular intervals.

In Figure 12 it is apparent that the manganese oxide in the Shirley Basin water is mostly removed by the sand filter. It is felt this removal is influenced by the comparatively high concentration of Ca^{2+} , (59 mg/l Ca^{2+} compared to 0.48 mg/l Mn). If a manganese oxide is prepared with similar concentrations of manganese oxide and calcium as the natural water, similar results are produced (Figure 12). However, if a manganese oxide is made at the same concentration of oxide but free of Ca^{2+} little removal is obtained.

Manganese, which was not oxidized before passing through the filter, was not removed by the sand (Figure 12).

COST OF TREATMENT

It is apparent from Figure 12 that the naturally occurring calcium in most Wyoming waters will act to cause effective removal of manganese by rapid sand filters provided the manganese is oxidized before filtration. Consequently, the cost of treating manganese by this method would only involve the cost of the oxidizing agent. For example, if the concentration of Mn^{2+} is similar to Shirley Basin water (0.4 mg/l), it would take 6.39 lbs of potassium permanganant per million gallons of water treated. If KMnO_4 costs \$1.50/lb the cost of this treatment would be \$9.58/MG. The cost per user is very small. If, for example, it was assumed that each user used 200 gallons of water per day, his cost for this service would be .19 cents per day.

If there had been no calcium in the water, the cost of adding the calcium would also be very small. For Shirley Basin water with a manganese concentration of 0.4 mg/l, it would take 7.48 lbs of lime per million gallons to raise the concentration of calcium to a sufficient level to cause the oxidized manganese to be removed by sand filtration. If lime cost \$1.00/lb, which is probably high, the cost of the lime treatment

would be \$7.48/MG or 0.14 cents/cap/day. The total cost of both oxidation and lime addition is small. That is for Shirley Basin water it would cost \$17.06/MG or .34 cents/cap/day.

The pH is not affected appreciable by the addition of lime if the alkalinity is about 10^{-4} to 10^{-3} eg/l. Most natural waters have an alkalinity equal to or higher than this value. In a water with an alkalinity of $10^{-3.5}$ eg/l and an initial pH of 7.3 the change in pH was only slight on addition of approximately 10^{-5} moles/l of lime. This is the approximate concentration of lime necessary to treat Shirley Basin water.

Of course, this is the cost of treatment if a sand filter plant is already in operation. Even for a very small town the cost of building such a plant would be close to \$100,000 which based on the population of Shirley Basin would be a cost of \$500/person. This cost would be inhibitive unless the water supply had to be treated for other water quality parameters than manganese concentration.

Most Wyoming communities have high Ca^{2+} concentrations. Therefore, for this treatment the only chemical that would be necessary to add would be one to oxidize the Mn^{2+} . However, Lovell is the only town in Wyoming which has both a manganese problem and available sand filters. Consequently, even though the cost of producing a manganese free water by using calcium as a filter aid is small, the process is economically unfeasible for most Wyoming towns due to lack of existing sand filters. In other areas of the United States such as the Southeastern United States, manganese could be removed at very little cost, because of the existance of many sand filter plants in that area.

In Lovell the additional cost per person for this treatment would be about .028 cents/person/day. The only chemical which need be added is KMnO_4 to oxidize the Mn^{2+} . This chemical could be added at the same time as the alum is added to give satisfactory results.

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SUMMARY OF CONCLUSIONS

1. The mathematical-chemical relationship derived to predict the most effective concentrations of Ca^{2+} for coagulation of manganese oxide particles and deposition on silica surfaces, can be used to predict effective concentrations of Ca^{2+} for removal of " $\delta\text{-MnO}_2$ " by model sand filters.
2. Differences in pH, affect the maximum effectiveness concentration of Ca^{2+} only slightly. However, precoating the sand with Ca^{2+} causes considerable change in the effectiveness of Ca^{2+} in aiding " $\delta\text{-MnO}_2$ " removal.
3. The cost of the treatment would be very small if a sand filtration plant is already in operation. It would cost approximately .34 cents/cap/day if both an oxidizing agent and calcium needs to be added. If the naturally occurring calcium is present only the oxidizing agent needs to be added at a cost of 0.19 cents/cap/day. The cost of this treatment, if a sand filter plant must be built, is high and would be economically unfeasible unless the filter plant provided other services. The benefit gained by removal of manganese is usually not worth building a filter plant for that sole purpose.

PUBLICATION RESULTING FROM PROJECT

Jenkins, S. R., Engeset, J. and V. R. Hasfurther, "The Effectiveness of Model Sand Filters for the Removal of Colloidal Manganese Oxides from Water Using Selected Cations as Filter Aids," Chemistry of Water Supply, Treatment and Distribution. ACS Advances in Chemistry Series, Ann Arbor Science Publishers, Inc., in press, will appear as a chapter in a hard back book in December 1973.

REPORT ABSTRACT

THE EFFECTIVENESS OF SAND FILTERS FOR THE REMOVAL OF COLLOIDAL MANGANESE OXIDES FROM WATER USING SELECTED CATIONS AS FILTER AIDS.

A mathematical-chemical relationship derived to predict the most effective concentrations of Ca^{2+} for coagulation of manganese oxide particles and deposition on a rotating disc type silica surface, was shown to predict the effective concentration of Ca^{2+} for removal of manganese oxide by model rapid sand filters. The concentration of calcium necessary to cause effective removal of manganese oxide was shown to be stoichiometric with the oxide concentration.

The relationship derived was acceptable in predicting the removal efficiency of both 1-inch ID - 4-inch deep and 4-inch ID - 3-foot deep sand filters. Differences in pH had little effect on the maximum effectiveness concentration of Ca^{2+} . However, precoating of the sand with Ca^{2+} , and rate of filtration were shown to greatly effect the concentration of Ca^{2+} for effective manganese oxide removal.

The cost of treating naturally occurring waters of Wyoming was shown to be small if rapid sand filtration plants were available. For example, most Wyoming waters contained enough Ca^{2+} that further additions of this cation would not have to be made. Consequently, the only cost would be the cost of oxidizing the manganese. If MnO_4^- was used as an oxidant the cost was shown to be about 0.19 cents/cap/day. In rare cases where lime would have to be added to increase the Ca^{2+} concentration, the cost would rise to only 0.34 cents/cap/day. Unfortunately, most Wyoming communities do not have existing sand filtration plants making the removal of manganese by this method uneconomical. The benefit gained by removing the manganese is usually not worth building a filter plant solely for that purpose.

Jenkins, Stephen R.

THE EFFECTIVENESS OF SAND FILTERS FOR THE REMOVAL OF COLLOIDAL
MANGANESE OXIDES FROM WATER USING SELECTED CATIONS AS FILTER AIDS.

Completion report to Office of Water Resources Research, Department
of the Interior, January, 1974. Washington, D.C.

KEYWORDS --- mathematical-chemical relationship*/ and filtration*/
coagulation/ manganese removal*/ filtration aids/ precoating/ cost of
treatment*/ pH/ precoating/ filtration rates/ complex-formation/
surface groups.