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R. Sage Murphy

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Fractionation

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TREATMENT OF LOW QUALITY WATER BY FOAM FRACTIONATION

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## ABSTRACT

### TREATMENT OF LOW QUALITY WATER BY FOAM FRACTIONATION

The removal of iron from Alaskan groundwaters by a foam fractionation technique has been shown to very effective. Finished waters with less than 0.2 mg/l iron have been produced from raw waters containing in excess of 25 mg/l. Ethylhexadecyldimethylammonium bromide was used as the principal foaming agent.

Low temperature oxidation of the ferrous iron tended to interfere with the removal rates, but high temperature oxidation followed by low temperature fractionation did not exhibit the same adverse influence.

All experiments were performed in four-liter laboratory batch columns. For the Alaskan environment batch processing is thought to have advantages over continuous processes because of the need for uncomplicated equipment.

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## INTRODUCTION

Most interior regions of the State of Alaska and northern Canada are confronted with serious domestic water supply problems in spite of seasonal excesses of surface water. Severe winters prevent the use of surface waters and scattered populations obviate the use of extensive distribution systems. Many remote locations, served only by small aircraft, make equipment and chemical costs prohibitive. In addition, technically trained personnel are lacking in most of these locations. Smallscale treatment plants, operated automatically or by untrained personnel, are definitely needed in much of the rural area in question. One treatment method which might meet this need is foam fractionation, the subject of this research,

High iron concentrations, a serious problem in permafrost and tundra areas, nearly always make it imperative that groundwaters be subjected to some treatment prior to consumption. Iron concentrations as high as 180 mg/l (1) have been found in shallow wells in the Kuskokwim River basin. High hardness is often found in many of these waters. Benson (2) described a batch treatment using lime for several small native villages. Although his method has proved to be effective in reducing both the iron and hardness, shipping lime to the remote areas is expensive. For example, shipping costs from Seattle, the nearest source for this chemical, exceed \$7 per 100 pounds, and shipment can only be made during three months of the year, otherwise airfreight must be used,

Where large quantities of water can be treated and distributed, conventional lime treatment is most often used for iron removal. Many areas, including a large part of the populated area surrounding the city of Fairbanks, are not served by a central municipal water supply system, and the residents must install their own wells and treatment systems. The treatment process used in this area is generally a water-softening ion-exchange resin. Some of the outlying villages revert to the process described by Benson (2), but no treatment at all is most common.

When foam fractionation is used for iron removal, ferrous iron is oxidized during an aeration step into particulate ferric iron, the colloid thus formed being amenable to foam removal. If the foaming procedure can be refined it should find use at many installations requiring a small water supply. Its use as a primary treatment method prior to water softening (if softening is a requirement) should reduce the clogging rates of the exchanger beds, thereby extending their useful lives as well as increasing the interval between regeneration cycles. For village installations the treatment cost economics should be reduced since virtually all surfactants can be purchased as dry chemicals. This, in conjunction with the fact that lower chemical concentrations are required than in lime treatment, should prove beneficial in terms of total chemical costs at the plant, particularly at locations where iron is significant but hardness is less than 200 mg/l.

The one energy requirement necessary for the foaming method is the electrical energy to power a compressor. There are few locations in the State of Alaska which could not provide the modest amounts of power required.

### PREVIOUS WORK

Hopper and McCowen (3) reported using a flotation process for water purification in 1952. Grieves (4) has reported results using a batch process to remove turbidity. His conclusions were that the process has a good deal of promise for the clarification of low-quality waters. Grieves found that aluminum, phosphate, and iron caused a serious interference in turbidity removal.

Grieves and Schwartz (5) studied a continuous process for turbidity removal. The reported results showed that iron and aluminum did interfere in turbidity removal, but that trivalent iron and turbidity could be removed by increasing both the detention time and the surfactant dosage.

Significant studies have been reported by other investigators on foam fractionation and flotation (6,7,8,9). The majority were concerned with the theory of the process rather than applied studies as reported herein. Much of the theory has been used in the experimental design on this project.

### PROCEDURE

All experiments done in this research were performed on a batch basis in equipment modeled after that used by Grieves (4). A Lucite column 150 cm tall with an inside diameter of 10 cm was used as the reaction vessel. A 40 micron pore-size diffusion disc was installed 1 cm above the column base. A Rotometer flow-meter measured the air rate being applied.

Excess foam was withdrawn at the 105 cm level into an aspirator jar by means of a vacuum, thus allowing measurement and analysis of the fractionated segment. The total height of the water never exceeded

100 cm (4 liters). Samples were withdrawn from the column through a port located at the 30 cm level.

All analytical analyses were performed in accordance with procedures outlined in Standard Methods (10). A Beckman DB spectrophotometer was used for all colorimetric tests.

The method of surfactant addition, air-flow rate, and temperature were varied in order to appraise the influence of each on the overall removal of iron from solution. When the surfactant was not added all at one time it was added incrementally in equal volumes over a predetermined time at 10 - 15 minute intervals.

The raw water source, with one exception, was obtained from a shallow well (45 ft.) located in a permafrost area near Fairbanks. Although the iron concentration of the raw water varied with the season, it remained in the 25-30 mg/l range. A few experiments were performed on a water which was relatively low in iron (3.5 mg/l) with no associated organics. Results were relatively good on these tests, but experimentation was stopped due to the source freezing prior to the completion of the series.

The primary foaming agent used was the cationic surfactant ethylhexadecyldimethylammonium bromide (EHDA-Br). A few other foaming agents were tested, but none proved to be as effective as EHDA-Br. These agents were: Alconox (a laboratory detergent), alkyl benzene sulfonate (ABS), stearic acid, and sodium lauryl sulfate. Each experimental run was considered complete when foaming ceased. This time rarely exceeded 120 minutes. Samples were withdrawn from the system at frequent intervals for chemical analysis.

## RESULTS

Of the various parameters investigated, water temperature had the greatest influence upon iron removal. Figure 1 shows the adverse influence which cold water had on the system. The operating mechanism was considered to be a combination of the following: 1) an increase in surface tension between the air bubbles and water; 2) a depression by temperature of the rate of adsorption of the iron precipitates on the foam; and 3) a decrease in the precipitate formation at low temperatures.

Figure 1 depicts eight tests, some of which were treated in slightly different manners. Each run on this figure is numbered, the numbers corresponding to those listed in Table 1: Summary of Results. The graphical results fall into two families of curves representing high and low iron removals. With one exception, #12, those run at low temperatures removed less than 50 percent of the iron while those run at temperatures in excess of 15° C had very good iron removal. Run #12, which had a low temperature (12°C), resulted in a 98.7 percent iron removal. This sample was collected on the previous day, allowed to come to room temperature during that day, and was refrigerated overnight prior to running the test. Run #14 was also stored for approximately the same length of time but it was never allowed to attain room temperature. This test resulted in a maximum removal of only 43.2 percent.

In order to determine whether the main influence on the percent removal was the degree of oxidation of the iron or the effect of temperature on physical processes, a sample of water was aerated until complete oxidation took place. Completeness of the reaction was determined by sampling the aerated mixture at different times, filtering the



sample through glass fiber filter paper, and analyzing the filtrate for iron. When no iron was found in the filtrate it was assumed the oxidation was complete, as only colloidal iron could be retained on the filter. The water was not allowed to exceed 15°C. Treatment of this sample by foam fractionation, Run #16, resulted in an iron removal of only 78.5 percent.

The above work points to the hypothesis that one of the primary factors involved is the temperature at which the colloidal particles are initially formed rather than the temperature at which the foam fractionation is performed. Further work is needed to elucidate the kinetics of the process,

Of the other foaming agents tested, none produced better than 19.7 percent iron removal. The results of these previously described agents are described in Table I.

In work done by Grieves (4) using EHDA-Br and similar laboratory apparatus and procedures, it was found that the optimum air-flow rate was 8000 ml/min. In the course of the research reported herein several tests were performed at different air-flow rates, maintaining all other variables constant. The results are shown in Figure 2. It is obvious that the lowest air-flow rate was the most efficient, the rate being an eightfold decrease from that found by Grieves in turbidity removal studies. Likewise, these results do not conform to Eckenfelder's statement that "Increasing the air results in higher removals because of increased surface area,..." (11).

Waters associated with permafrost regions are often characterized by high concentrations of dissolved organic matter. In the water used in most of these experiments, the organic concentration, as tannins

and lignins, was between 2-4 mg/l. Approximately 50 percent removal of this material was obtained on all runs which removed more than 90 percent of the iron, resulting in a finished water with no color and a pleasant taste.

#### SUMMARY AND CONCLUSIONS

The foregoing studies on the foam fractionation removal of impurities in low-quality Alaskan groundwaters revealed that the process may have merit for some installations: the individual home, a mining camp, or a small village in a remote location. Finished waters of better quality than specified by the USPHS Drinking Water Standards (12) have been produced under laboratory conditions from raw waters containing in excess of 25 mg/l iron.

It is recognized that a continuous process will more closely meet the demands of most present-day situations. However, when water presently costs up to eight cents per gallon in Alaskan remote areas, a batch process appears worthy of trial. Using a batch process will reduce the complexity of the equipment, an important consideration for areas inhabited by technically untrained individuals.

Temperature was found to directly influence the removal efficiency of iron to a greater degree than any other single parameter. This single factor may cause the process to be more difficult to operate in many northern areas unless a source of heat or a catalyst is utilized for the oxidation step in the process.

#### FUTURE STUDIES

Studies are planned or are in progress by this and other organizations which are concerned with the following:

1. Detailed studies to determine the oxidation rate of iron under prototype conditions.
2. Laboratory studies to determine the particle size of the colloids formed under various temperatures.
3. Testing of other cationic surfactants.
4. The construction of a small prototype unit in the field, using available materials and local labor.
5. Economic analysis of a batch treatment process for small installations.

#### ACKNOWLEDGEMENT

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Table 1: SUMMARY OF RESULTS

Run No.	SURFACTANT		Air Flow ml/min	Temperature <sup>3</sup> °C	Iron Removal percent
	Type <sup>1</sup>	mg. Added			
1	1	180	6400 <sup>2</sup>	23.5	73.5 <sup>4</sup>
2	"	"	"	room	96.8 <sup>4</sup>
3	"	"	"	"	85.4 <sup>4</sup>
4a	"	"	6600	?	59.5
b	"	"	4200	?	77.6
c	"	"	3000	?	71.2
d	"	"	1100	?	82.5
5	"	240	1250 <sup>2</sup>	?	99 +
6	"	150	" <sup>2</sup>	?	88.7
7	"	"	"	?	67.1
8	"	"	"	?	95.3
9	"	"	"	8.3	17.8
10	"	300	"	21.0	98.2 <sup>4</sup>
11	"	"	"	12.0	35.7
12	"	225	"	12.0	98.7 <sup>4</sup>
13	"	"	"	11.7	27.8
14	"	"	"	9.0	43.2 <sup>4</sup>
15	"	"	"	57.0	99.6 <sup>4</sup>
16	"	"	"	15.0	78.5
17	2	750	"	9.7	4.1 <sup>4</sup>
18	3	225	"	8.3	2.9
19	"	"	"	22.5	19.7 <sup>4</sup>
20	4	225	"	13.0	3.9
21	5	150	"	8.3	2.6
22	1	240	" <sup>2</sup>	22.0	95.9 <sup>4</sup>
23	"	225	16000	22.7	70.3
24	"	"	8000	21.3	94.3

- <sup>1</sup> Type of surfactant: 1= EHDA-Br  
2= Alconox (laboratory detergent)  
3= ABS  
4= Stearic Acid  
5= Sodium Lauryl Sulfate
- <sup>2</sup> Foaming agent added in increments over the first 45 minutes of run.
- <sup>3</sup> Average temperature of the first 30 minutes of the run.
- <sup>4</sup> Raw water was allowed to react at least 24 hours prior to the start of the run.

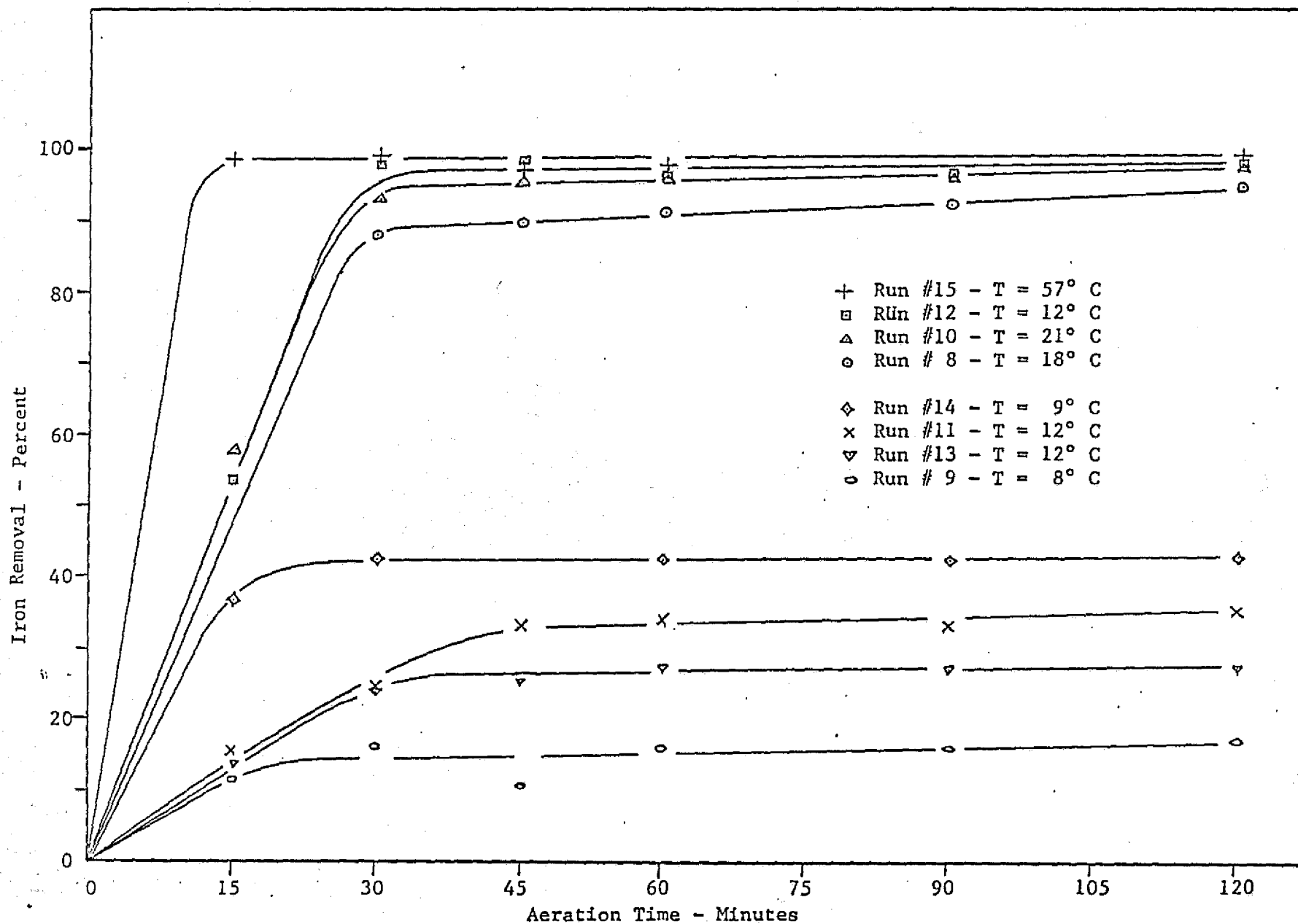


FIGURE 1: Influence of Temperature on Percent Iron Removal over Total Aeration Time

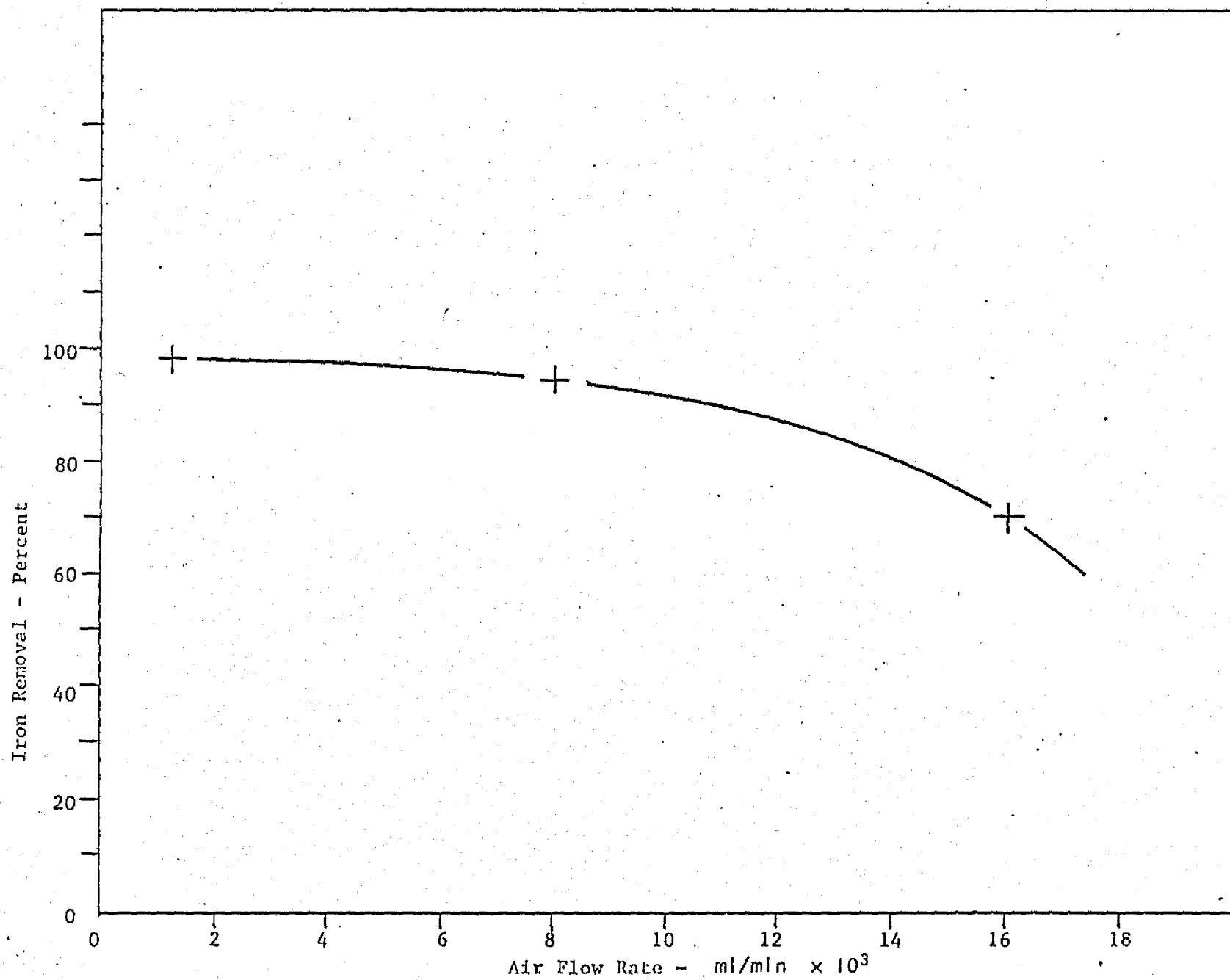


FIGURE 2: Influence of Air Flow Rate on Percent Iron Removal