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FINAL REPORT — THE USE OF ALUM AND ACTIVATED SILICA FOR 100 AREA PROCESS WATER COAGULATION

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BY

W. C. A. WOODS

PILE TECHNOLOGY SECTION
ENGINEERING DEPARTMENT

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By

W. C. A. Woods

Pile Technology Section
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FINAL REPORT - THE USE OF ALUM AND ACTIVATED SILICA
FOR 100 AREA PROCESS WATER COAGULATION

INTRODUCTION

Production rates of the Hanford reactors can be increased in proportion to the quantity of process cooling water which can be supplied to them. This water must be of such a quality that slug and tube corrosion rates are acceptable, the gross activity of the effluent water must not be excessive, the concentration of specific radioactive isotopes constituting a radiological hazard must be minimized, and the film formation rates should be as low as possible. In the Hanford water treatment process, the filter plants are the controlling factor in determining the quality of the water, and one of the elements limiting the quantity of water.

Technological advances have allowed increases in the reactor production rates, with a concomitant increase in process water demand. This demand increased to the extent that, by 1951, the filter plants were limiting the quantity of water which could be supplied to the reactors. While the capacity of these plants can be increased by the construction of additional filters, this is expensive, since each filter unit costs in the neighborhood of \$500,000. A major development effort was therefore undertaken to develop methods of increasing the capacity of the existing filter plants. This report presents the results of this development work* from its inception in 1951 to its conclusion in 1954.

SUMMARY

A series of tests has been carried out commencing in 1951 and concluding in 1954 for the purpose of developing methods of increasing the 100 Area filter plant capacity. These tests were almost exclusively on a full-plant scale, and the results are therefore quite conclusive.

* The production tests covered by this report are listed in the Appendix, Page 26.

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The results of these tests showed the following:

1. Filtration rates in all 100 Area filter plants of 6.0 gpm/ft^2 are technically feasible and operationally practical.
2. The total flow rate through the filter plants can be easily increased to take advantage of these filtration rates.
3. The quality of the process water is entirely satisfactory, and is improved because of lower film formation rates.

These rates were achieved by the following processes and modifications:

1. Use of alum as a coagulant and activated silica as a coagulation aid.
2. Use of 0.7 to 0.8 mm effective size anthrafilt as a filter bed media for filtration rates above 5.5 gpm/ft^2 .
3. Minor modifications to the filter effluent piping and flume structure to reduce flow resistance.
4. Maintenance of iron content of process water below 0.01 ppm.

The filtration rates and filter plant throughputs obtained during these tests are 2.3 times the design rates of all filter plants except the 100-K Plants, for which the design capacity is increased by a factor of 1.3. These filtration rates are among the highest achieved in this country on a continuous basis.

The modifications necessary to achieve these flow rates will cost approximately \$1,600,000 at all areas. In addition, the research and development effort has cost about \$400,000, for a total of \$2,000,000. Operating cost increases will be relatively small, and are estimated to be offset by increased production rates due to lowered film formation rates.

These capacity increases have saved approximately 17 million dollars in the capital costs of additional filtration units. These units would have otherwise been required to achieve the K-Pile design flow rates and the flow rates which will be provided by the current Reactor-Plant Modification Program at the other reactor areas. Thus this

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development work has made possible a net savings of fifteen million dollars. The alum-activated silica coagulation process has therefore resulted in substantial economic gains, and it can be concluded that the adoption of this process in all areas has been entirely sound.

A. REVIEW OF PREVIOUS WORK

Process water treatment at Hanford consists of purification of the water by coagulation and filtration through rapid sand type filters. Additional chemicals are added for pH adjustment, organic growth inhibition, and corrosion inhibition. The purification operation is the most important in this treatment process, both in terms of capital and operating costs, and in terms of its effect on overall water quality. The capital cost of the filter plants is typically 10 - 15 per cent of the total cost of a reactor plant. A considerable incentive exists, therefore, to increase the allowable filtration rate per square foot of filter area. Such an increase would reduce the capital cost of a filter plant for a required total flow rate. In plants already operating, the necessity of adding additional filter units to achieve higher flows could be eliminated. Since the production level is proportional to the process water flow rate, such increases in filter plant capacity would therefore decrease the cost of obtaining this increased production.

Early in 1951, it became apparent that process water flow rates in excess of the capabilities of the filter plants could be effectively utilized. A development effort was then initiated in an attempt to effect the required increase. Prior to this time, the coagulant in use was that specified⁽²⁾ since the start of the Hanford water plants, ferric sulfate. The allowable filtration rate using this chemical was known from experience to be limited when the concentration of iron and turbidity in the river water was high, as is the case during the spring of each year. During such periods, these impurities are not efficiently coagulated, so that they tend to pass through the filters, a phenomenon known as break-through. High film formation rates are the result of this break-through.

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As the filtering rate increases, this tendency also increases. Consequently, each filter must be removed from service at increasingly frequent intervals for backwashing, if the specified quality of water is to be maintained.

A survey⁽¹⁾ showed that aluminum sulfate (alum) used as a coagulant and activated silica as a coagulating aid might achieve the desired result of increasing filtration rates. Alum had been tested for use prior to startup of the plant, but was discarded in favor of ferric sulfate when aluminum was found to be a more virulent film-former than iron. However, laboratory tests had shown that by adjusting the coagulation and filtration pH to about 7.0, the aluminum concentration would be at a minimum,⁽²⁾ and therefore the film formation due to aluminum would also be minimized. A limited amount of experience with alum and silica had been also obtained in the 200 Area filter plants, which showed higher filtration rates might be achieved. Based on these predicted characteristics of alum-silica coagulation, a plant scale test was started in the 100 F Area using alum as a coagulant in October, 1951.⁽³⁾ The results^(4, 5) of this test showed that, contrary to previous experience, film formation rates were negligible. In addition, the effluent water activity and corrosivity obtained with alum treated water were found to be no greater than those with ferric sulfate treated water.

Because of these encouraging results, an activated silica preparation and addition facility was constructed, and activated silica addition at the F Reactor was started⁽⁶⁾ at the end of December, 1951 and continued through December, 1952. This test thus covered a complete cycle in river water conditions. The results showed⁽⁷⁾ that (1) filtration rates could be increased from 2.7 to 4.5 gpm/ft² of filter surface area regardless of river water quality, (2) with proper adjustment of the alum and silica addition rates, film formation was negligible, and (3) by modifying the filter beds so that clogging tendencies were reduced, filter rates as high as 5.0 gpm/ft² could probably be achieved continuously.

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By July, 1952, sufficient information had been obtained to recommend the use of alum and activated silica in the design of the 100-K filter plants. This recommendation was adopted, and the design filtration rate was changed from 2.6 to 4.5 gpm. ft². The resulting reduction in required filter area decreased the cost of these filter plants by about ten million dollars.

The incentive for immediate application of this process to the existing 100 Areas, where current process water demands could still be met with the ferric sulfate process, was not as well defined. Operating costs (principally chemical consumption) were higher with alum than with ferric sulfate coagulation. In addition, a capital expenditure for activated silica addition equipment was required. Balancing these higher costs was a gain in production resulting from the lower film formation rates. It thus was necessary to demonstrate that these production gains were of sufficient magnitude to warrant adopting the process.

Starting in June, 1952, a number of tube leaks and severely corroded slugs were experienced at the F Pile, ^(8, 9) which at the time was the only area which had used alum. The potential savings in construction costs at the K Area water plants and the future applicability of the alum-silica treatment to existing 100 Areas therefore required that the cause of this phenomenon be defined and corrective measures taken.

The remainder of this document presents the results of the further testing which ultimately led to the adoption of alum-silica process for process use, and the application of this process to high filtration rate operation.

**B. APPLICATION OF THE ALUM-ACTIVATED SILICA COAGULATION
PROCESS WITH LOW FILTRATION RATES**

Immediate application of the alum-silica process to the 100 Areas water treatment was, as indicated previously, dependent on two considerations. Of immediate importance was the necessity of assurance that

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the severe pitting of slugs and tubes encountered at the F Pile was not an inherent characteristic of the alum process. Accordingly, a rather comprehensive series of laboratory and plant-scale tests were started to determine the cause of the pitting attack, and to develop a method of preventing this attack. (10,11)

The results of these series of tests have been detailed in other reports. (12,13) The basic cause of the pitting was found to be an erosion-corrosion type of attack. The mechanism apparently depended on the presence of particulate matter in the water, which eroded the metal surfaces as it was swept along by the high velocity water in the pile coolant passages. Data from these corrosion tests showed that similar, though not as extensive, attack had taken place in other areas supplied with ferric sulfate-treated water. Further examination showed that this attack was inhibited by sodium dichromate, which had been added to the process water until April, 1952. (14) The process water at F was found to contain a somewhat higher concentration of the solids; this apparently only aggravated the attack in the absence of dichromate. After dichromate addition was started in November, 1952, no further evidence of the attack was found regardless of the coagulation process used.

With this pitting problem solved, it was necessary to determine uniform slug jacket corrosion rates in alum water. For this purpose, a number of tubes containing weighed regular metal pieces were charged in those piles supplied with alum-coagulated water to which the dichromate was added. After these tubes were discharged, the slugs were cleaned, weighed, and the weight loss determined. The conventional method of presenting these weight loss data is as a function of temperature. If this temperature can be taken as the temperature at the water-slug surface interface, it can be readily calculated by standard methods. (15) This method was chosen for presenting the data from these tests. Figure 1 shows the data obtained with alum coagulated water compared with that

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obtained with ferric sulfate water. The ferric sulfate curve was taken from previous work, ⁽¹⁵⁾ as that representing data under approximately equivalent conditions, as shown in the following table.

TABLE I

COMPARISON OF OPERATING CONDITIONS FOR CORROSION DATA

	<u>Ferric Sulfate</u>	<u>Alum-Silica</u>
Tube Power, KW	357-390	321-595
Flow Rate, gpm	25-26	26-40
Exposure Time, days	128-206	109-206

The conditions for the alum-silica data are seen to be somewhat more severe. Reference to Figure 1 shows that the corrosion rates in alum water are certainly no worse than in ferric sulfate water.

More recently, a correlation⁽¹⁶⁾ of the slug jacket corrosion data has shown that an empirical correction factor should be added to the calculated temperature. This method was not used here, since the correction factors were not available for the ferric sulfate data. The method used here is considered adequate for comparative purposes. The correction factor should affect the shape of the two curves of Figure 1 more than their position relative to each other. Therefore, the curves should not be extrapolated.

In addition to corrosion, two other factors are important technically in establishing the effects of water treatment. These are the activity of the effluent water, and the film-forming characteristics in the reactor. Additional data concerning these effects were obtained during the course of the tests conducted.

The data obtained from the F Pile test showed that the activity of the effluent water was about the same for the two types of water. ⁽⁷⁾ The major difference was a considerable increase in the Mn⁵⁶ activity with alum. This isotope has a 2.6 hour half-life, and is not considered to

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represent a radiological hazard. Experience at the piles using alum during the winter of 1952 and spring of 1953 completely confirmed these earlier data. Figure 2 shows the range of effluent activities for alum and for ferric sulfate treated water during this period. Much of the variation in activity is due to different retention times and power levels between areas. Radiochemical analyses of the effluent water again showed that the manganese activity contributed the major portion of the high activity. (17)

Similarly, operating experience in the alum areas completely confirmed the expectation that film formation rates could be controlled by correct rates of addition of alum and silica. It was found that, as has been previously observed and reported, that film which might be formed when the rates were not correct, would be removed when the rates were properly adjusted. The most striking evidence of this reduction in film formation is obtainable from the records of purges which were conducted during the period January - August, 1953. Eight purges were necessary at the four piles using alum water. In the two piles utilizing ferric sulfate water, 23 purges were necessary. The purges at the piles using alum were all at the C Pile and occurred shortly after the newly constructed silica addition equipment was put in operation in February, 1953. It was found that the silica produced in this facility did not aid coagulation during certain times. The difficulty was traced to improper mixing of the sodium silicate and dilute sulfuric acid. No further film formation was encountered after the equipment was modified to provide sufficient mixing.

The operating experience and data obtained in these series of tests demonstrate, therefore, that process water produced by alum-silica coagulation was equally as good as ferric sulfate water corrosion-wise and effluent activity-wise. Furthermore, film formation rates were demonstrably less with the alum water. Consequently, it can be concluded that the technical feasibility of the alum silica process has been firmly established with filtration rates in the range 3.0 - 4.5 gpm/ft².

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Immediate applicability of the alum process would therefore be determined by the relative cost of the two processes. A test was started to operate the water plants in a controlled manner so that comparable cost information could be obtained.⁽¹⁸⁾ The results of this test are shown in Figure 3 for the period January - December, 1953. It can be seen that the unit cost of treating water with alum and silica was somewhat greater during the first four months of the year. However, after April, the alum costs were either lower than or the same as ferric sulfate costs. The annual costs of these two treatment methods were found to be very nearly the same. Because of the lower film formation rates, it can be estimated that approximately 4200 MWD/year of production would be gained by using alum. The estimated cost of activated silica facilities suitable for use was estimated to be \$109,000 and extra operating costs of \$20,000/year would also be incurred. Amortizing this amount in three years, the cost of this added production is seen to be about \$12/MWD, compared to about \$15-17/MWD for the unit cost of irradiation.

Therefore, the alum-silica process was specified as the coagulation process for all areas in November, 1953, because of its economic superiority and technical feasibility. By March, 1954, all areas were using this treatment.

C. APPLICATION OF THE ALUM-SILICA PROCESS TO HIGH FILTRATION RATES

In 1953, a review of the available technical information showed that flow rates considerably in excess of those then in use could be effectively used in the piles, and the power levels raised in proportion.⁽¹⁹⁾ These new flow rates corresponded to filtration rates of 5.5 - 6.0 gpm/ft² in all areas except C and H. Although a limited amount of work had been done previously with filtration rates of 5.0 gpm/ft², the desired rates required a considerable improvement in filter plant performance.

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The allowable rate at which water can be filtered in the rapid-sand type filter units used at HAPO depends on two effects. First, as the water containing the floc particles passes through the filter bed, these particles clog the flow passages in the bed, and so an increased driving force (the head difference across the filter bed) is required for a constant flow rate. The maximum driving force available is fixed by the plant construction, which determines the level of water above the filter bed, and in the clearwells. In practice, a throttling valve is placed between the filter outlet and the clearwell. The total driving force must thus equal the sum of the resistances of the filter bed and valve (plus other fixed resistances in the interconnecting piping). When the filter is first placed in operation, the bed resistance is low, and the valve adjusts automatically so that the desired flow rate is achieved. As the bed resistance increases, the valve opens, maintaining a constant flow. Eventually, (when the valve has opened to its maximum position) the flow will decrease. The filter must then be removed from service and backwashed to flush out the accumulated floc. The length of time the filter is in service - the filter run time - depends on the amount of floc accumulated (which depends on the filtration rate), the tendency of the floc to clog the filter, and the depth and size of the filter bed medium. Practically, a minimum run time must be maintained so that the operator can backwash the filters and attend to his other duties. Experience at HAPO indicated that this minimum run time is 4 - 7 hours, depending on the number of filters in the plant.

Process water quality considerations impose a further restriction. As the length of filter runs increases beyond a certain time, the concentration of floc and other impurities in the filtrate increases, slowly at first but at an increasing rate. The filter must be backwashed before the concentration has increased to the extent that rapid film formation rates occur in the pile. The length of filter runs under these conditions decreases with increasing filtration rates. The activated silica serves

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to produce larger and stronger floc particles which do not pass readily through the filter bed. These particles clog the filter bed at an increased rate, however, and the result is a higher head loss.

Practical filter plant operation, therefore, requires adjustment of the alum and silica feed rates so that the floc produced is tough enough to minimize impurity breakthrough, but so that the floc does not clog the filters too fast. Minimizing breakthrough requires increased chemical addition rates, which then act to increase the head loss. The hydraulic characteristics (i. e., the resistances external to the filter bed) of the filter must be such that the required quantity of water of the specified quality can be produced with filter run times not exceeding the minimum allowable.

Tests⁽²⁰⁾ conducted in the 100-D and 100-F filter plants in 1953 showed that the desired quantity of water could be produced at filtration rates of up to 6.0 gpm/ft². In addition to minor changes in the filter plant structure, which increased the available head across the filters, it was found necessary to change the filter bed to an all-anthafilt type for filter rates above 5.5 gpm/ft². With these alterations, filter run times of up to 8 hours were estimated based on hydraulic considerations only. Preliminary tests showed that impurity breakthrough should not become excessive under the proposed operating conditions. On this basis, it was recommended that filtration rates of up to 6.0 gpm/ft² be used as the design basis for the Reactor Plant Expansion program then being scoped.⁽²²⁾

In order to verify the conclusion that the quality of the process water produced at high filtration rates would be satisfactory under all treatment conditions, a plant test was initiated in the 100-D Area.⁽²³⁾ The primary purpose of this test was to demonstrate that high quality water could be produced at filtration rates up to 6.0 gpm/ft². In addition, the test would provide an opportunity to develop procedures and practices as required for continuous and routine operation of the filter plants under

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these conditions. The modifications to the filter plant structure required for hydraulic considerations were completed at the end of January, 1955, and the test was started immediately afterward.

The 100-D filter plant consists of 16 rapid sand filters with a surface area of 1152 square feet per filter and 16 sedimentation basins connected to the filters through a flume. The plant is physically divided into two symmetrical parts, and independent operation of each half is standard practice. For the test, 50,000 gpm of untreated water was passed through seven filters and basins on one side of the plant. This flow rate supplied about 90 per cent of the total filter plant demand. The corresponding filter rate was slightly in excess of 6.0 gpm/ft². It was not possible to supply the total demand at the high rate because of hydraulic limitations in the inlet water piping and flumes. The high flow was necessary so that the flash mixing time would be reduced to the same time available for this program when the entire plant was operating with the high filtration rates. Table II summarizes the test operating conditions, and compares them to design conditions.

TABLE II

SUMMARY OF PLANT OPERATING CONDITIONS FOR HIGH
FILTRATION RATE TEST

	<u>Test</u>	<u>Design</u>
Throughput per side, gpm	50,000	18,000
Flash mix time, minutes	1.1	3.1
Flocculation time, minutes	19	45
Sedimentation time, hours	1.15	2.75
Filtration Rate, gpm/ft ²	6.0	2.6

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Starting on February 12, 1954, filtration rates were gradually increased until the proposed conditions listed above were reached on March 18, 1954. These conditions were maintained until July 26, 1954, when the test was terminated. The test thus covered the period when difficult water treatment conditions are encountered. A successful demonstration of the proposed conditions during this time was considered definitive.

The results of the test are shown graphically in Figure 4, which shows the filter run times, film formation rates, and river turbidity during the test. It can be seen that filter run times were never below four hours, and improved during the latter part of the test. These later run times are believed most representative because sufficient operating experience had been gained by that time. Film formation rates were generally acceptable, except for several periods when very high rates were encountered. In all cases, these high rates could be attributed to malfunctioning of filter plant equipment or to lack of experience with the process.

Corrosion rates of slugs in the D Pile exposed during the test period are shown in Figure 5, which compares them to the low filtration rate alum data shown in Figure 1. As can be seen, no difference in corrosion rates was found. The activity of the D Pile effluent is shown in Figure 6 compared to the effluent activities of other areas. No significant difference in activities is apparent. Isotopic analysis of the river water showed no significant difference to exist between the effluent from D-Reactor and other reactors.

D. DISCUSSION OF RESULTS

The data and operating experience presented above show that operation of Hanford filter plants at filtration rates of up to 6.0 gpm/ft² is both technically feasible and operationally practical. The performance of the filters will be improved beyond that found in the test by the use of the all-anthracite filtering media. By the use of this material the head

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loss will be reduced. The chemical feed rate can then be increased to insure against breakthrough. The result will necessarily be longer filter runs. Further improvements in operational techniques at these rates is desirable, however, and the test indicated two areas in which improvement would be of most value. Specifically, the test showed that improved methods of analytical control of water quality and more rapid detection of malfunctioning equipment would be of considerable benefit.

Water quality control is primarily a matter of maintaining the water quality such that film formation in the pile is negligible. The method currently used is the measurement of film formation by the change in panellit pressure, and the rate of addition of alum and/or activated silica is changed as required to maintain a constant panellit pressure. This method has succeeded under current filter plant conditions, i. e., relatively low filtration rates, since the rate of film formation has not been found to be excessive, and chemical addition rates could be changed in sufficient time to correct the water quality. Because of the large volume of water stored between the filter plant and the pile, a time lag of about four hours occurs between these points. As long as film formation rates are not rapid, the method described above is satisfactory.

The test results showed that at high filtration rates, film formation rates with poor water quality were increased to the point that pile shut-downs would occur because of the increased panellit pressures. This situation arises because at the high flow rates filter plant operating conditions cannot be changed rapidly enough to correct the poor quality. Under these conditions, water quality control should be carried out at the filter plant.

Fast experience has shown that film formation is apparently a function of iron concentration in the filtered water; the data obtained show that the upper limit is about 0.01 ppm. These conditions are always based on time-averaged iron concentrations as the iron concentration in individual samples has been found to scatter over a wide range. This scatter is a

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result of the insensitivity of the iron analytical method in the desired concentration range, and to the distinct possibility of contamination of the sample. In addition, the analytical method requires some 30-45 minutes per sample. Experience during the test showed that sampling of individual filters at least every hour would be desirable so that break-through could be rapidly detected. This amount of analytical control is beyond the capabilities of the present analytical procedures, and would require a trained chemist on duty to run them.

During the latter part of the test, an analytical device based on light scattering principles became available. It was found that the results from this instrument correlated with the iron concentrations, and required only a few minutes per sample. Further testing with this device since the termination of the test has shown that water quality control based on this instrument is entirely feasible. It is believed that by this means, sufficient time will be available for purging, if required, and that, more important, closer control of water quality will be possible.

Malfunctioning of chemical feed equipment or operational errors resulted in high film formation rates on a number of occasions. Such events are almost certain to happen, and if immediately corrected will cause little trouble. On these occasions, however, the trouble was not located until a considerable quantity of poor quality water had been produced. The solution to the problem is the installation of an alarm system which detects incorrect chemical feed equipment operation. Incorrect alum feed operation can be detected by a change in the conductivity or in the pH of the solution leaving the feeder. A conductivity cell supplied with the alum feed solution has since been installed and has proven entirely satisfactory. Low alum concentration this solution can be detected in only a few minutes after the occurrence of the difficulty causing the low feed rate. A low pressure alarm on the silica feed line can be used to protect against low silica feed. Equipment difficulties with the silica feed facility were confined, however, to the rotameters, these glass tubes became coated with silica gel so that an incorrect feed rate was indicated. Frequent cleaning eliminated this problem.

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The short filter runs which had been experienced prior to June prompted a test⁽²⁴⁾ in which sulfuric acid was added to reduce the coagulation pH to 7.0 as laboratory tests had shown that better coagulation could be obtained at this pH. Additional chlorine was also added to aid in treating the increased amount of organic material present in the river at this time of year. Although the filter runs increased shortly afterwards, it is believed that improved methods of testing water quality and more rigid inspection of equipment were more likely the important factors. Acid addition for the purpose of improving coagulation alone does not appear to be of great benefit. On July 6, the activated silica preparation method was altered, so that 92 per cent of the caustic content was neutralized rather than 57 per cent. Again, laboratory tests showed that some improvement should be expected, but the plant test did not confirm this.

In general, the test showed that more frequent than normal checking of equipment and filtered water quality was necessary at the high filtration rates. The holdup time in the filter plant decreased very markedly at this high throughputs, and incorrect chemical addition rates were quickly reflected in the quality of the filtered water. New operational procedures are required to minimize poor water quality, and the test⁽²⁵⁾ now in progress by the Process Sub-Section of the Manufacturing Department should provide the additional operational information required. The results so far obtained from this test have shown that excellent water quality and filter runs of six to seven hours can be obtained routinely at a filter rate of 6.0 gpm/ft².

E. ECONOMIC CONSIDERATIONS

The original incentive for developing the alum-silica process was the desire for greater throughputs through the existing filter plants. As has been demonstrated, filtration rates up to 6.0 gpm/ft² can be successfully maintained on a year-round basis using this coagulation process. A corresponding maximum filtration rate using ferric sulfate is not known

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exactly. Experience at Hanford has shown that the value of 2.6 gpm/ft^2 used as a design basis for the DR, H, and C water plants is extremely conservative. It is estimated that a more realistic value may be as high as 4.5 gpm/ft^2 . The applicability of activated silica as a coagulation aid for ferric sulfate has not been developed. Preliminary laboratory experiments have shown that process conditions must be closely controlled if any benefit is to be obtained. Further studies were dropped when the superior film forming properties of alum water were discovered, and it appeared that the increased rates could be obtained with alum.

Assuming, then, that filtration rates as high as 4.5 gpm/ft^2 could be maintained with ferric sulfate, the capital cost savings associated with the higher alum-silica rates can be computed on the basis of the proposed water flow rates.⁽²⁶⁾ These rates are shown in Table III, together with the corresponding filtration rate. The last column in the table shows the additional filter area required for a filtration rate of 4.5 gpm/ft^2 .

TABLE III

COMPARISON OF FILTER AREAS REQUIRED FOR ALUM-SILICA
AND FERRIC SULFATE COAGULATION

<u>Area</u>	<u>Raw Water Flow Rate, gpm</u>	<u>Required Filtration Rate, gpm/ft²</u>	<u>Additional Filter Area Required for 4.5 gpm/ft^2 Maximum Filter Rate</u>
B	82,000	6.0	4600
D	95,000	5.4	3700
DR	70,000	6.0	3800
F	82,000	6.0	4600
H	82,000	4.5	---
			<u>16,700</u>

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In general, as the filter area is increased, it is necessary to add a corresponding amount of sedimentation and flocculation capacity. The cost for an additional filter with an area of 1152 square feet, plus the associated sedimentation and flocculation basins, has been variously estimated. The value used here is among the lower of these estimates, and is \$500,000 or \$430/sq ft. The added cost would then have been approximately \$7,000,000. This amount would increase the reactor plant expansion costs for B, D, DR, and F Areas by about 20 per cent.

Operating costs at the high filtration rates were found to be somewhat higher, as shown in Figure 7. The increased costs are almost entirely due to increased chemical consumption. Maintenance costs are also somewhat higher, since the instrumentation and equipment required more frequent checking, and equipment breakdown can not be tolerated. Further experience has shown, however, that the chemical costs can be reduced so that they are very nearly the same, regardless of filter rates. In addition to this increased operating cost, an additional capital expenditure is required to convert the activated silica facilities to a more permanent nature and to increase their capacities. Many of these facilities were constructed as experimental facilities of a temporary nature. The capital cost for this purpose has been estimated at \$300,000.⁽²⁷⁾ In view of the large savings as a result of the increased filter rates, the cost increases are insignificant.

The overall economics of this development effort are also very favorable. These are summarized in the Table below:

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TABLE IV

ECONOMIC ANALYSIS OF ALUM ACTIVATED SILICA

Gains from Increased Filtration Rates	\$17,000,000
Costs:	
Activated Silica Addition Facilities (All Areas)	\$ 1,100,000
Modification to Filter Plants	500,000
Research and Development Costs (Including Experimental Facilities)	400,000
	<hr/>
Total	\$ 2,000,000
Net Gain	\$15,000,000

It was assumed that any increased operating costs would be offset by production gains due to lower film formation rates.

F. CONCLUSIONS

The capacity of the 100 Area filter plants can be increased to that corresponding to a continuous filtration rate of 6.0 gpm/ft² by the use of the alum-activated silica coagulation process. This conclusion is supported by numerous plant scale tests under all conditions of river water conditions. These tests have shown that sustained filtration rates of 6.0 gpm/ft² are technically feasible, operationally practical, and economically sound.

As a corollary, the choice of alum for the design of the 100-K filter plants, and the use of filtration rate of 6.0 gpm/ft² as a design basis for the current Reactor Plant Modification program (Project CG-558) are entirely justified.

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G. ACKNOWLEDGEMENTS

Full scale tests require the co-operation of the plant operating personnel for their successful prosecution. The operating personnel of the 100-D filter plant all devoted extra time and effort to the goal of achieving the high filtration rates. In particular, N. H. Skarshaug, the 100-D Power Supervisor and his assistants, E. R. Hill and W. R. Kiplinger, were unfailing in their efforts. The author is especially indebted to W. R. Conley, who made numerous and important contributions. These suggestions and advice were invaluable.

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APPENDIX

This report is based on the work performed under the following production tests:

1. "PT 105-503-E, The Use of Activated Silica as a Coagulation Aid for Aluminum Sulfate," and Supplements A through D.
2. "PT 105-508-E, The Use of Aluminum Sulfate at 100-D Area," and Supplements A and B.
3. "PT 105-513-E, 100 Areas Process Water Quality Evaluation Tests," and Supplement A.
4. "PT 105-517-E, 100 Areas Filter Plant Tests," and Supplements A and B.
5. "DT 105-524-E, 100 Areas Filter Plant Hydraulic Limit Tests."

This report constitutes the final report on all of these tests.

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FIGURE 1

COMPARISON OF IN - PILE SLUG JACKET CORROSION RATES IN
ALUM - ACTIVATED SILICA AND FERRIC SULFATE - TREATED
WATERS

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FIGURE 2
COMPARISON OF EFFLUENT ACTIVITIES OF ALUM - ACTIVATED SILICA AND FERRIC
SULFATE WATERS FOR 1953.

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FIGURE 3
UNIT COST OF 100 AREA WATER TREATMENT, 1953
EXCLUDES SODIUM DICHROMATE COSTS

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FIGURE 4

183-D FILTER PLANT OPERATIONAL RECORD
 FILTER RATES: 2/12 - 2/18, 5.2 GPM/FT²
 3/18 - 3/26, 6.1 GPM/FT²

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FIGURE 5
IN - PILE SLUG JACKET CORROSION RATES WITH HIGH
FILTRATION RATES

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FIGURE 7
WATER TREATMENT CHEMICAL COSTS FOR HIGH FILTRATION
RATES IN 1954

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