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U.S. DEPARTMENT OF ENERGY

**Development of a Cost-Effective Environmental
Compliance Technology for Stripper Well Brines**

QUARTERLY REPORT FOR THE PERIOD

October 1, 199³₂, Through December 31, 199³₂

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RESEARCH SUMMARY

TITLE: Development of a Cost-Effective
Environmental Compliance Technology for
Stripper Well Brines

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REPORTING PERIOD: October 1, 1992 - December 31, 1992

MAJOR ACHIEVEMENTS

During this quarter, work on the critical pH studies was completed and work was initiated on determining the catalytic effect of one metal on another. In particular, the studies of copper's effect on aluminum were completed.

OVERALL PROJECT OBJECTIVES

In order to demonstrate to the EPA that brines from both stripper oil and marginal gas wells in the Appalachian Basin are capable of being treated and disposed of by discharge to streams in an environmentally safe manner, the existing research effort on stripper oil well brines will be continued and expanded to examine the range of brines produced from marginal gas wells.

The specific object of the research is to demonstrate that the characteristics of wastewater from stripper oil wells and marginal gas wells are sufficiently similar to be treated under a standardized treatment methodology, that the environmental impacts of the discharge of treated brines from both stripper oil and marginal gas wells can be adequately regulated, and that the inclusion of marginal gas wells in the

same category as stripper oil wells is appropriate, especially for wells operating in the Appalachian Basin.

WORK PERFORMED DURING THE PREVIOUS QUARTER

Not applicable (this is the first reporting quarter).

WORK SCHEDULED FOR THE REPORTING PERIOD

During this reporting period, the kinetics study was extended to include the analysis of higher concentrations of copper and aluminum. Field work consisted of the analysis of Cooper and Kane brines with respect to metals concentrations. Other laboratory experimental work included a continuation of the studies of the effect of sand thickness and the angle of aeration unit on the system's efficacy. The process studies were also to be extended to include the effect of the presence of the retention tank and the temperature of the laboratory treatment system.

WORK PERFORMED DURING THE REPORTING PERIOD

I. Laboratory Experiments

Catalytic Effect Studies

During this quarter, work on the critical pH studies was completed and work was initiated on determining the catalytic effect of one metal on another. In particular, the studies of copper's effect on aluminum were completed. This series of tests proved that the experimental techniques used for the measurement of catalytic effects are effective.

Since the experimental procedures have been established, the next series of experiments will determine the effect of aluminum on copper, lead, and zinc. Each metal will be studied at two different concentrations of aluminum, 0.01% and 0.05%. These experiments will require at least six runs for each metal. To date, the copper and lead experiments have been completed. Analysis of these runs is currently in progress.

Process Studies

The process studies initiated earlier involving the effects of sand thickness in the filtration unit and angle of inclination of the aeration unit were continued in order to obtain more conclusive results. In addition, the effects of the presence of the retention tank and the temperature of the system were investigated.

First, a new set of experiments was designed in order to study in more detail the effect of the angle of the aeration unit on the iron removal from the brine. These new experiments investigated the effect of varying the angle of the aeration unit from 1° to 45° . Results from these experiments indicated a small improvement of the treatment with an increase in the angle of the aeration unit. In general, the iron removal from the brine was more effective as the angle of inclination of the aeration unit increased. In addition, an increase in the angle of aeration unit had a slight positive effect on the pH of the brine. That is, as the unit's angle increased, the pH of the brine increased as well. A higher pH consequently had a positive effect on the iron removal from the brine. Figure 1 and Tables 1 through 4 summarize the results of this particular study. The function of the sand in the filtration unit is to remove the ferric ions formed during the treatment process and to remove complex iron molecules that may be suspended in the brine solution. In order to study the effect of the thickness of the sand in the filtration unit, the sand thickness was varied from 2.5 inches to 5.0 inches. The flow rate was held constant at 3.0 bbl/d, while the inlet concentration of iron was varied from 50 to 200 ppm at 50 ppm increments. The results of this phase of the work seem to indicate that sand thickness has no significant effect on the brine treatment. The slight variations seen in iron removal from the brine can probably be explained by the fact that as sand thickness increases, the brine's retention time in the sandbox increases. However, this effect could be considered negligible. Supporting data for this conclusion can be found in Tables 5 through 8. Results of this aspect of the work are summarized in Figure 2.

The function of the retention tank is to provide sufficient time for the oxidation reaction to be completed so that the ferrous ion is reduced to the ferric ion. In order to study the effect of the

retention tank of the overall brine treatment process, data was collected for four runs in which the retention tank was removed from the system. This data was compared to data from four previous runs in which the retention tank was in place. All other variables were kept constant for this experiment.

Data from this study shows that the presence of the retention tank has a significant impact on removal of iron from the brine. The effect of the retention tank on the brine treatment became more pronounced for brine which contained a higher concentration of the lighter iron. Tables 5 through 8 show the data collected with no retention tank present. Figure 3 shows graphically the effect that the retention tank has on the brine treatment.

The final part of the process studies involved the effects of the temperature on the brine treatment. In general, the temperature plays an important role in chemical reactions. The reaction rate is strongly dependent on temperature. In order to study the sensitivity of brine treatment to temperature, a set of experiments was designed in which the temperature of the system was 44°F, 54°F, and 66°F. The temperature of 44°F was the lowest temperature that could be maintained in the laboratory facility. Results from the temperature study showed that temperatures could be a significant factor in brine treatment. The difference between treatment at 44° and 54° was quite significant. The lower temperature decreases the amount of iron that is removed from the system. The general conclusion drawn from this study is that lower temperatures should be avoided for a more effective brine treatment. Relevant data is presented in Tables 9 through 11 and in Figure 4.

II. Field Experiments

General Testing

During this reporting period, field experiments were conducted with the brines originating from the Cooper and Kane sandstones. It is interesting to note, that oil recovery is realized from these formations through primary production and secondary recovery. Moreover, these formations produce substantial quantities of natural gas. The Cooper sandstone, following depletion, has been converted to

natural gas storage. The concentration of iron in these two brines before treatment is relatively low (about 13 ppm for Cooper brine and 8 ppm for Kane brine). The results of the experiments show that low inlet iron concentration helps to increase the efficiency of the treatment process. Under most conditions, the iron concentration after treatment is below 3 ppm for Cooper brine and below 1 ppm for Kane brine. The flow rate being tested in this period was up to 16.5 bbl/D and temperature range was between 25 and 55°F. An attempt to run the test below the temperature of 25°F failed because the brine froze when it passed through the aeration unit.

Table 1 summarizes the effect of temperature and flow rate on the efficiency of the treatment of the Cooper brine. As was concluded in the previous report, more iron can be removed at higher temperature with the same flow rate, while in the same range of temperature, the efficiency of iron removal decreases as flow rate increases. The data in Table 12 are the statistical results from more than 150 samples taken from the field experiments, Figure 5 shows a specific example demonstrating the effect of temperature. The experiment began at noon and ended at 9:00 PM. The temperature changed from 52°F to 36.5°F during the test. The curve in Figure 5 shows that iron concentration after the treatment increases as the temperature continuously decreases with time. This is an example of the effect of a wide temperature change during one run. For most tests conducted in the field, the temperature did not change as dramatically, and the efficiency of the treatment is quite stable within one run.

As for the Kane brine, because of its low iron concentration, the effects of temperature and flow rate are not so obvious. The experimental results show that at a temperature above 32°F and a flow rate between 4.5 and 16.5 bbl/D, the iron concentration after the treatment is reduced below 0.5 ppm, which means practically all the iron has been removed by the treatment. The only exception to this was a test conducted when temperature dropped below 32°F at a flow rate of 12 bbl/D. In this case, the average iron concentration after the treatment is 0.94 ppm. However, this test had to be stopped when temperature dropped below 25°F because the brine froze as it passed through the aeration unit.

It is important to note that the pH value for both Cooper brine and Kane brine is about 7.0-7.1. The limestone columns can hardly increase the pH value any higher. Experiments conducted using four limestone columns, one column and no columns show that when brine with a high pH value is treated, limestone column could be eliminated from the system.

Besides iron concentration, other metals were also analyzed with the field test samples. Table 13 shows the approximate concentrations of Aluminum, Barium, Calcium, Magnesium, Manganese, Sodium and Strontium in both Cooper brine and Kane brine. The concentrations of other metals, such as Arsenic, Beryllium, Cadmium, Chromium, Copper, Lead, Nickel and Zinc, are listed below 0.5 ppm in both brines. In light of the accuracy of the metals analysis, any metal with a concentration below 0.5 ppm is considered non-exist. Hence, the removal of the metals listed in Table 13 by the treatment so far is not significant. More analysis is needed to find an effective way to remove these metals.

WORK SCHEDULED FOR THE NEXT REPORTING PERIOD

The catalytic studies should be completed during the next reporting period. In particular, the analysis of zinc will be completed and work will begin on the catalytic effects of copper on lead and zinc. After these two combinations are completed, lead and zinc will be studied as catalysts, which will conclude the catalytic studies. The field studies will continue with further investigation of ways to remove some of the heavy metals. In particular, the effectiveness of the system in removing organics will be examined.

TABLE 1. Effect of Angle of Aeration Unit on Iron Removal

TOTAL IRON	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50
INLET	50.30	51.81	49.42	49.61	50.71	49.98	50.20	49.53	50.75	51.11	50.89	49.29
EXIT1	43.42	49.19	47.26	48.33	47.89	47.06	48.49	46.98	47.81	50.48	49.93	48.08
EXIT2	27.41	39.91	41.31	42.88	44.13	43.51	46.52	43.27	46.07	45.13	44.81	43.88
EXIT3	26.85	39.36	41.29	42.50	42.91	43.20	44.15	43.24	45.90	45.27	44.72	42.44
EXIT4	2.05	5.67	8.22	8.48	8.16	8.62	10.57	11.42	12.30	12.05	12.72	12.68
Aeration Angle = 45 °							Aeration Angle = 1 °					

pH	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50
INLET	1.99	2.00	1.98	1.99	1.99	1.99	1.99	1.99	2.00	2.00	1.99	2.00
EXIT1	5.71	5.66	5.65	5.64	5.64	5.64	5.63	5.62	5.62	5.64	5.64	5.63
EXIT2	6.14	6.08	6.07	6.07	6.07	6.08	6.08	6.09	6.08	6.08	6.10	6.09
EXIT3	6.69	6.66	6.65	6.65	6.65	6.65	6.38	6.40	6.39	6.40	6.41	6.40
EXIT4	6.45	6.35	6.29	6.22	6.17	6.12	6.10	6.09	6.06	6.02	6.03	6.02

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE SECOND LIMESTONE COLUMN

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

TABLE 2. Effect of Angle of Aeration Unit on Iron Removal

TOTAL IRON	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50	TIME 5:10
INLET	97.50	100.97	99.01	101.11	100.70	100.35	97.37	98.95	100.33	99.35	97.92	100.50	100.19
EXIT1	96.58	98.68	96.97	99.04	97.44	97.66	97.35	97.34	97.47	98.96	97.63	100.19	98.46
EXIT2	88.63	94.29	96.72	98.49	95.48	96.56	97.84	96.97	97.82	98.54	96.66	98.10	98.73
EXIT3	88.52	92.68	94.32	98.24	95.34	96.81	96.27	95.25	96.04	97.04	96.49	98.66	96.80
EXIT4	19.15	34.72	39.35	41.25	45.93	46.86	40.77	38.45	38.10	37.27	39.88	38.02	39.76
Aeration Angle = 1 °							Aeration Angle = 45 °						

pH	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50	TIME 5:10
INLET	1.53	1.52	1.53	1.55	1.55	1.54	1.54	1.53	1.53	1.53	1.53	1.54	1.53
EXIT1	5.26	5.25	5.14	5.16	5.16	5.15	5.13	5.12	5.11	5.11	5.10	5.10	5.10
EXIT2	5.72	5.70	5.67	5.67	5.66	5.65	5.63	5.61	5.61	5.60	5.60	5.59	5.60
EXIT3	6.07	6.05	6.04	6.04	6.03	6.03	6.35	6.36	6.36	6.35	6.34	6.35	6.35
EXIT4	6.17	6.02	5.98	5.98	5.85	5.83	5.78	5.72	5.71	5.71	5.72	5.74	5.72

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE SECOND LIMESTONE COLUMN

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

TABLE 3. Effect of Angle of Aeration Unit on Iron Removal

TOTAL IRON	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50
INLET	147.31	148.32	149.98	149.44	150.22	150.89	149.19	150.85	148.14	150.07	151.51	151.01
EXIT1	144.69	145.50	148.11	147.58	148.58	148.78	148.00	148.46	146.72	147.04	149.10	149.07
EXIT2	133.63	143.78	146.55	146.21	148.11	148.31	146.43	144.59	143.41	144.55	143.95	144.03
EXIT3	133.15	141.05	144.70	143.73	146.15	142.87	143.05	144.16	140.64	141.57	139.35	143.77
EXIT4	45.28	68.56	73.77	76.12	80.49	77.93	80.98	84.68	85.27	86.64	82.96	84.71
Aeration Angle = 45 °							Aeration Angle = 1 °					

pH	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50
INLET	1.77	1.77	1.78	1.78	1.77	1.78	1.77	1.78	1.78	1.77	1.77	1.78
EXIT1	5.29	5.26	5.25	5.25	5.25	5.25	5.23	5.24	5.25	5.24	5.24	5.24
EXIT2	5.76	5.75	5.76	5.77	5.77	5.77	5.80	5.80	5.80	5.80	5.79	5.79
EXIT3	6.42	6.41	6.39	6.37	6.37	6.36	6.10	6.10	6.10	6.10	6.10	6.10
EXIT4	5.58	5.56	5.52	5.47	5.44	5.44	5.46	5.45	5.45	5.42	5.41	5.40

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE SECOND LIMESTONE COLUMN

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

TABLE 4. Effect of Angle of Aeration Unit on Iron Removal

TOTAL IRON	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50
INLET	197.02	201.73	198.23	199.92	199.19	201.41	198.90	201.60	199.36	196.33	198.85	198.74
EXIT1	196.30	198.66	197.23	199.36	200.22	198.56	198.30	200.69	199.76	197.27	196.70	197.46
EXIT2	194.15	193.05	194.25	195.38	196.36	197.52	193.90	198.71	196.56	194.93	195.66	193.08
EXIT3	189.24	189.01	191.18	188.55	194.84	194.48	190.26	189.34	195.87	192.19	189.10	193.08
EXIT4	123.14	133.73	136.09	135.91	139.96	141.01	135.85	134.13	135.23	129.84	131.01	131.42
Aeration Angle = 1 °							Aeration Angle = 45 °					

pH	TIME 1:00	TIME 1:20	TIME 1:40	TIME 2:00	TIME 2:20	TIME 2:40	TIME 3:10	TIME 3:30	TIME 3:50	TIME 4:10	TIME 4:30	TIME 4:50
INLET	1.69	1.70	1.70	1.69	1.70	1.69	1.69	1.70	1.70	1.69	1.69	1.70
EXIT1	5.19	5.16	5.14	5.13	5.14	5.14	5.12	5.11	5.12	5.12	5.12	5.12
EXIT2	5.73	5.72	5.71	5.71	5.72	5.72	5.70	5.69	5.69	5.70	5.70	5.69
EXIT3	6.06	6.04	6.04	6.04	6.04	6.03	6.34	6.33	6.34	6.33	6.34	6.33
EXIT4	5.29	5.25	5.23	5.24	5.27	5.23	5.23	5.24	5.23	5.25	5.26	5.26

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE SECOND LIMESTONE COLUMN

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

TABLE 5. Effect of Sand Thickness on Iron Removal

TOTAL IRON	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	48.48	49.25	50.21	49.48	95.47	95.33	96.65	96.50	142.96	143.15	147.62	147.00	172.19	178.57	179.71	177.02
EXIT1	48.75	47.87	48.48	48.86	93.63	91.72	94.96	95.58	138.24	143.94	146.49	145.83	171.81	178.01	178.44	176.83
EXIT2	42.51	43.51	45.55	46.25	92.16	91.96	93.88	93.07	137.36	142.25	143.77	143.98	172.19	173.92	175.07	174.48
EXIT3	42.66	42.03	43.39	45.10	88.83	91.12	90.95	92.87	134.53	142.25	142.01	142.53	167.60	174.75	175.38	174.83
EXIT4	24.10	25.35	26.95	28.36	58.39	64.65	67.00	69.10	104.04	107.88	111.58	110.57	123.97	128.73	128.01	130.46

pH	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	1.80	1.80	1.79	1.80	1.73	1.72	1.73	1.72	1.68	1.68	1.68	1.68	1.55	1.54	1.54	1.54
EXIT1	5.49	5.46	5.44	5.44	5.38	5.38	5.37	5.37	5.29	5.29	5.29	5.30	5.18	5.18	5.17	5.17
EXIT2	5.91	5.90	5.90	5.88	5.80	5.80	5.80	5.79	5.74	5.74	5.74	5.73	5.62	5.62	5.63	5.61
EXIT3	6.26	6.26	6.24	6.23	6.16	6.15	6.15	6.15	6.09	6.09	6.09	6.09	6.00	6.01	6.00	5.99
EXIT4	6.31	6.27	6.23	6.22	6.16	6.14	6.12	6.10	6.04	6.02	6.02	6.00	5.96	5.95	5.92	5.91

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE AERATION UNIT

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

SAND THICKNESS = 2.5 inches

AERATION ANGLE = 1 °

TABLE 6. Effect of Sand Thickness on Iron Removal

TOTAL IRON	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	50.91	47.95	49.48	49.35	95.03	95.91	93.88	97.15	142.49	143.35	144.38	146.34	181.79	183.23	174.12	184.69
EXIT1	48.30	48.51	48.75	48.14	94.56	95.19	93.03	95.73	141.20	143.11	142.91	141.55	178.34	179.28	173.91	182.37
EXIT2	46.35	44.97	46.05	47.44	93.47	93.04	93.29	94.04	141.88	143.76	140.07	139.65	178.05	173.62	173.71	179.56
EXIT3	45.85	45.20	45.83	47.10	91.65	89.85	92.87	93.04	139.28	141.12	141.03	137.76	176.85	171.15	171.40	176.10
EXIT4	21.39	23.13	25.61	29.05	53.90	59.65	65.33	68.60	92.87	99.44	106.96	106.57	117.04	124.38	126.66	129.23

pH	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	1.63	1.64	1.63	1.64	1.60	1.60	1.60	1.60	1.62	1.61	1.61	1.61	1.60	1.60	1.60	1.60
EXIT1	5.41	5.38	5.37	5.38	5.31	5.32	5.32	5.33	5.32	5.32	5.32	5.31	5.24	5.22	5.23	5.24
EXIT2	5.77	5.78	5.76	5.76	5.70	5.70	5.70	5.70	5.68	5.68	5.68	5.68	5.65	5.65	5.65	5.65
EXIT3	6.08	6.09	6.09	6.09	6.03	6.03	6.01	6.01	6.00	6.00	6.00	6.01	6.00	6.00	6.00	5.99
EXIT4	6.28	6.24	6.23	6.20	6.08	6.05	6.03	6.01	6.00	6.01	5.98	5.97	5.94	5.92	5.90	5.90

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE AERATION UNIT

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

SAND THICKNESS = 5 inches

AERATION ANGLE = 1 °

TABLE 7. Effect of Sand Thickness on Iron Removal

TOTAL IRON	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	49.06	50.51	50.39	49.42	95.97	96.38	98.34	97.66	144.32	147.51	150.01	147.71	179.64	184.14	183.49	186.28
EXIT1	48.33	50.04	49.75	50.57	94.71	95.21	94.80	94.90	142.29	143.12	145.76	143.65	178.66	179.77	181.14	182.84
EXIT2	43.04	43.45	43.57	46.68	91.32	91.82	90.49	90.07	141.48	143.43	145.61	138.75	174.93	178.35	179.51	178.07
EXIT3	41.93	41.29	42.59	44.25	90.49	89.42	89.61	88.86	137.09	140.95	142.41	138.73	172.88	175.60	179.15	177.88
EXIT4	22.87	24.37	26.73	27.36	52.30	60.15	64.52	67.73	95.78	97.20	109.74	107.46	120.20	124.04	128.43	128.10

pH	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	1.90	1.90	1.89	1.90	1.83	1.83	1.82	1.81	1.75	1.75	1.74	1.74	1.68	1.67	1.67	1.67
EXIT1	5.52	5.52	5.52	5.52	5.43	5.43	5.42	5.43	5.34	5.35	5.35	5.35	5.26	5.24	5.25	5.24
EXIT2	5.96	5.96	5.96	5.96	5.88	5.89	5.90	5.90	5.82	5.82	5.82	5.82	5.73	5.73	5.73	5.74
EXIT3	6.33	6.33	6.31	6.32	6.25	6.25	6.25	6.24	6.18	6.18	6.18	6.18	6.12	6.12	6.12	6.11
EXIT4	6.68	6.60	6.54	6.50	6.43	6.39	6.37	6.35	6.23	6.23	6.21	6.20	6.08	6.06	6.02	6.00

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68°F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE AERATION UNIT

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

SAND THICKNESS = 5 inches

AERATION ANGLE = 1 °

TABLE 8. Effect of Sand Thickness on Iron Removal

TOTAL IRON	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	50.41	53.24	51.17	51.36	98.23	99.32	98.56	97.14	145.96	148.54	151.27	147.24	185.13	182.22	184.34	185.31
EXIT1	50.38	51.47	49.96	50.59	97.39	96.87	96.87	93.14	144.79	147.04	145.08	145.30	182.99	181.04	183.18	182.75
EXIT2	42.95	45.60	45.69	45.31	93.33	93.73	91.80	90.23	142.56	140.94	142.52	141.90	177.03	177.57	178.68	177.32
EXIT3	43.49	40.51	43.16	44.52	92.74	92.05	90.01	90.52	141.56	141.38	140.10	140.71	170.84	177.68	177.18	176.22
EXIT4	24.01	26.04	25.43	26.92	58.52	62.70	63.01	66.32	101.68	104.06	107.09	108.99	119.67	128.88	127.89	128.43

pH	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	1.78	1.78	1.76	1.76	1.74	1.74	1.74	1.74	1.70	1.70	1.69	1.68	1.64	1.64	1.64	1.64
EXIT1	5.44	5.40	5.39	5.37	5.30	5.30	5.30	5.31	5.27	5.27	5.27	5.27	5.20	5.19	5.18	5.18
EXIT2	5.91	5.88	5.88	5.88	5.83	5.83	5.83	5.83	5.78	5.78	5.78	5.78	5.72	5.71	5.71	5.71
EXIT3	6.34	6.34	6.33	6.32	6.26	6.27	6.27	6.27	6.23	6.23	6.23	6.23	6.16	6.16	6.16	6.16
EXIT4	6.40	6.41	6.40	6.38	6.28	6.26	6.25	6.25	6.18	6.19	6.16	6.15	6.08	6.06	6.04	6.04

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 68°F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE AERATION UNIT

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

SAND THICKNESS = 2.5 inches

AERATION ANGLE = 1 °

TABLE 9. Effect of Temperature on Iron Removal

TOTAL IRON	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	49.32	48.19	51.37	51.76	97.43	94.23	100.49	96.22	141.88	143.44	145.81	142.60	175.13	180.79	174.91	178.44
EXIT1	47.76	47.38	49.87	48.79	97.16	94.47	96.65	94.46	139.57	140.91	141.14	141.09	174.49	173.69	171.56	172.67
EXIT2	47.02	46.19	48.20	49.89	93.17	92.31	97.20	93.78	138.75	141.15	141.90	141.67	172.54	171.15	171.80	172.00
EXIT3	46.32	45.75	47.66	46.96	91.83	92.13	95.01	93.73	137.46	140.58	138.60	139.23	170.87	169.55	171.00	171.56
EXIT4	32.00	34.12	37.59	37.76	73.93	73.03	79.42	82.39	117.10	122.75	126.40	123.74	156.05	157.05	156.68	157.56

pH	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	1.89	1.88	1.88	1.88	1.82	1.82	1.82	1.82	1.76	1.75	1.76	1.76	1.71	1.71	1.71	1.70
EXIT1	5.40	5.39	5.38	5.38	5.29	5.29	5.28	5.28	5.21	5.21	5.21	5.20	5.13	5.13	5.12	5.12
EXIT2	5.75	5.75	5.74	5.75	5.67	5.67	5.67	5.67	5.60	5.60	5.60	5.60	5.56	5.56	5.55	5.55
EXIT3	6.09	6.08	6.07	6.07	6.02	6.02	6.02	6.03	5.95	5.95	5.96	5.96	5.92	5.92	5.92	5.92
EXIT4	6.36	6.31	6.28	6.25	6.13	6.14	6.13	6.13	6.05	6.05	6.05	6.04	6.00	6.00	5.99	6.00

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 44 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE AERATION UNIT

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

SAND THICKNESS = 2.5 inches

AERATION ANGLE = 1 °

TABLE 10. Effect of Temperature on Iron Removal

TOTAL IRON	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	49.58	47.78	48.78	49.19	99.07	102.87	102.31	103.43	146.44	145.82	146.71	145.64	186.68	185.32	186.14	183.39
EXIT1	46.96	47.18	47.91	48.21	98.81	100.66	101.12	101.68	146.04	146.34	143.22	143.44	186.09	184.57	185.27	184.57
EXIT2	44.59	44.98	45.91	45.43	98.36	100.54	100.19	100.89	145.00	143.37	145.20	144.33	183.34	181.98	183.38	180.37
EXIT3	44.31	44.10	45.57	44.84	96.39	100.61	98.97	97.70	144.06	141.16	142.52	141.92	181.84	180.42	182.78	181.69
EXIT4	24.05	25.71	26.71	27.01	63.03	67.19	70.13	70.80	107.39	105.80	107.43	106.37	137.23	139.81	140.25	139.32

pH	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	1.92	1.93	1.92	1.91	1.85	1.85	1.85	1.84	1.82	1.82	1.82	1.82	1.77	1.76	1.77	1.76
EXIT1	5.52	5.50	5.48	5.48	5.36	5.37	5.36	5.36	5.32	5.32	5.32	5.30	5.24	5.24	5.24	5.23
EXIT2	5.92	5.90	5.90	5.90	5.82	5.81	5.81	5.81	5.76	5.76	5.76	5.76	5.71	5.71	5.71	5.72
EXIT3	6.29	6.29	6.30	6.29	6.22	6.22	6.21	6.21	6.17	6.17	6.17	6.17	6.12	6.12	6.12	6.12
EXIT4	6.55	6.53	6.52	6.50	6.36	6.35	6.34	6.34	6.25	6.24	6.25	6.24	6.15	6.14	6.15	6.15

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 54 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE AERATION UNIT

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

SAND THICKNESS = 2.5 inches

AERATION ANGLE = 1 °

TABLE 11. Effect of Temperature on Iron Removal

TOTAL IRON	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	50.33	53.30	48.91	49.37	98.93	98.09	98.73	99.56	143.90	144.16	145.90	147.10	180.32	181.35	180.17	180.27
EXIT1	50.83	53.23	49.90	48.45	98.59	98.95	98.42	99.12	140.64	144.36	142.53	144.76	179.49	180.18	179.21	176.92
EXIT2	49.48	52.13	48.27	47.65	98.33	97.32	98.00	96.99	138.83	142.62	142.87	142.43	175.09	178.59	177.85	175.73
EXIT3	49.78	46.01	47.65	47.66	96.34	95.73	94.96	94.86	138.15	141.34	136.62	140.67	175.90	177.28	173.39	175.32
EXIT4	23.91	22.36	25.84	27.37	61.71	61.58	64.58	66.37	98.14	100.63	100.09	103.13	130.00	130.81	131.79	130.87

pH	TIME 0:50	TIME 1:00	TIME 1:10	TIME 1:20	TIME 2:10	TIME 2:20	TIME 2:30	TIME 2:40	TIME 3:30	TIME 3:40	TIME 3:50	TIME 4:00	TIME 4:50	TIME 5:00	TIME 5:10	TIME 5:20
INLET	1.82	1.82	1.81	1.81	1.79	1.79	1.79	1.78	1.75	1.75	1.76	1.75	1.67	1.68	1.67	1.67
EXIT1	5.45	5.43	5.42	5.41	5.34	5.35	5.34	5.35	5.29	5.29	5.28	5.29	5.21	5.21	5.21	5.22
EXIT2	5.82	5.82	5.80	5.80	5.75	5.75	5.75	5.75	5.70	5.70	5.71	5.71	5.65	5.65	5.65	5.65
EXIT3	6.18	6.18	6.17	6.18	6.12	6.12	6.12	6.14	6.09	6.09	6.10	6.10	6.05	6.05	6.06	6.05
EXIT4	6.58	6.54	6.49	6.47	6.31	6.30	6.29	6.29	6.20	6.20	6.20	6.19	6.11	6.10	6.10	6.09

FLOW RATE = 3.014 BBL/DAY

TEMPERATURE = 64 °F

EXIT 1 - AFTER THE FIRST LIMESTONE COLUMN

EXIT 2 - AFTER THE AERATION UNIT

EXIT 3 - AFTER THE AERATION UNIT

EXIT 4 - AFTER THE SAND FILTRATION UNIT

SAND THICKNESS = 2.5 inches

AERATION ANGLE = 1 °

**Table 12. Effect of Temperature and Flow Rate on Brine Treatment
(Iron Concentration after Treatment, ppm)**

Temperature F	Flow Rate (bbl/D)			
	4.5	8.0	12.0	16.5
32 - 50	0.3 - 0.9	0.8 - 2.0	1.4 - 2.5	2.0 - 3.0
50 - 55	0.3 - 0.4	0.4 - 0.7	0.7 - 0.9	1.0 - 1.7

Table 13. Concentration of Heavy Metals in Cooper Brine and Kane Brine

Brine Location	Concentration of Metals (ppm)						
	Al	Ba	Ca	Mg	Mn	Na	Sr
Cooper Brine	1.7	< 0.5	9500	190	1.5	2300	12.0
Kane Brine	1.3	3.5	6500	160	1.0	2900	19.0

Figure 2. Effect of Sand Thickness on The Treatment

Figure 3. Effect of the Retention Tank on the Treatment

Figure 4. Effect of Temperature on The Treatment

Figure 5. Effect of Temperature on Brine Treatment (field unit)

END

DATE

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5/3/94