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TREATMENT OF MINE WATER AS A FACTOR IN THE MINERAL PRODUCTION IN SOUTHEASTERN KANSAS

By

E. D. KINNEY

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TREATMENT OF MINE WATER AS A FACTOR IN THE MINERAL PRODUCTION IN SOUTHEASTERN KANSAS

By E. D. KINNEY[1]

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ILLUSTRATIONS

ABSTRACT

Methods of neutralizing economically the acid in mine waters and recovering iron as a commercial by-product are compared and discussed from the standpoint of the mine operators in the lead and zinc district of southeastern Kansas. That increased production of lead and zinc would result from the adoption of a feasible method of treatment of mine waters is indicated.

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[1] Metallurgist, State Geological Survey of Kansas, and Associate Professor of Metallurgy, Department of Mining and Metallurgical Engineering, University of Kansas.

INTRODUCTION

Purpose of investigation.—The principal function of the Kansas Geological Survey is to promote the mineral industries of the state. In the southeastern Kansas zinc- and lead-mining industry, a serious problem confronting operators is the disposal of mine waters that contain large amounts of both acid and iron. The value of production in the Tri-State District is now almost $18,000,000 a year, zinc concentrates constituting 83 percent of this amount and lead concentrates 17 percent. Approximately 27 percent of production in the district is produced in Kansas, and the annual value of zinc and lead production in Kansas is about $4,860,000. Of the Kansas total, $1,000,000 represents the value of the yield from the Baxter Springs area, where the disposal of mine water is a problem. The operators in this area are deterred from an increase in ore production by difficulties in disposal of enlarged quantities of acid mine waters. There is undoubtedly a limit to the amount of untreated mine water that can be dumped into surface drainage without danger of harmful effects on the streams. Indeed, damage suits now pending may lead to a curtailment of lead and zinc production in Kansas.

The purpose of the investigation that is here reported was to study two closely connected problems,—how deleterious features of the mine water can best be reduced or removed, and whether the valuable iron content of the mine waters can be recovered economically. All citizens, including the mine operators, are concerned in safeguarding the quality of surface waters, and this is a special function of the Division of Sanitation of the State Board of Health, which, accordingly, is also deeply interested in the problem of mine-water disposal in southeastern Kansas. The commercial production of iron from this source would benefit the state.

Methods and content of present study.—(1) Stream samples. Samples were obtained from all streams that might be contaminated by zinc- and lead-mine water originating or flowing through Kansas and entering Oklahoma. The map shown in figure 1 indicates the locations where such samples were obtained, and gives both the total iron content and the acidity (expressed as pH) for each sample. Included also are the same data for samples collected by the State Water and Sewage Laboratory, working with the Tri-State Ore Producers' Association. The investigations of the Water and Sewage Laboratory were also made in 1940.

(2) Analysis of samples. Table 10 shows the anaylses of all samples. Each analysis reports the amount of total iron, iron in solution, and total acidity, expressed in parts per million parts of water, and the pH of the samples.

(3) Laboratory tests. Tests were made on the efficiency of water from Spring river, which is alkaline and therefore neutralizes acid, in precipitating iron from mine water, which is acid. A tabulation of results of these tests, showing the effects of various amounts of river water, analyses of the precipitated iron mixture, and various other data, is given in table 11. Ten parts of river water neutralized one part of mine water, and 78 percent of the iron was precipitated as hydroxide. Use of a larger amount of river water causes a greater percent of the iron to be precipitated.

(4) Iron and acid content of mine water. Figure 1 shows a part of the Kansas zinc- and lead-mining field, which may be divided into two areas, according to the iron and acid content of water from mines located in these areas. In the Baxter Springs area the mine waters contain large amounts of these substances. Waters from the Treece-Hockerville area, on the other hand, seem to contain only harmless amounts of iron and acid. The ore produced in the Waco area occurs in a calcareous gangue, and mine waters from this district (not shown on the map) cause no significant stream pollution.

(5) The cost of chemicals for purification is given in table 4.

(6) A map of the Baxter Springs drainage district (figure 2) is presented.

Acknowledgments.—Special thanks are due to the following persons who have given valued aid in connection with the study leading to this report: Earnest Boyce, Director, Division of Sanitation, State Board of Health, Lawrence, for analyses of water samples; H. H. Utley, Manager of the St. Louis Smelting & Refining Company, Baxter Springs; O. W. Bilharz, Bilharz Mining Company, Baxter Springs; Frank C. Brewster, Baxter Springs; Chester Scott, Federal Mining Company, Baxter Springs; James L. Smith, Baxter Chat Company, Baxter Springs; and Evan Just, Secretary, Tri-State Ore Producers' Association, Picher, Okla.

Discussion of Problem

Iron pyrite is probably the source of most of the iron and acid that is present in the mine waters under consideration. In the presence of water and air, the pyrite is converted to iron sulphate, as shown in the following equation:

$$FeS_2 + 3.5O_2 + H_2O = Fe_2SO_4 + H_2SO_4$$

pyrite + oxygen + water = iron sulphate + sulphuric acid

The zinc-lead ore occurs in Mississippian (Keokuk and Warsaw) limestone, and associated with varying amounts, generally small, of iron sulphide (pyrite and marcasite). The ore-bearing strata are overlain by the Cherokee shale, of Pennsylvanian age. The basal part of the Cherokee shale is exposed at places along the belt of outcrop west and north of Spring river, principally in the vicinity of Baxter Springs, and the shale also contains pyrite and marcasite. The upper workings of some mines in the Baxter Springs region penetrate the shale formation. It is in this area where the greatest trouble with mine water is experienced. Alternate working and closing of mines has aggravated this condition, inasmuch as oxidation of the iron sulphide occurs when the mines are dewatered and solution of the oxidized substances occurs when the water rises during periods of inactivity.

Mine waters in the Treece and Waco areas contain no great amount of objectionable impurities, and will not be discussed.

The following is a list of prominent mines in the Baxter Springs area, together with analyses and other data.

TABLE 1. *Water from mines in the Baxter Springs area.*

Mine and map index number	Direction from Baxter Springs	Water pumped gal. per 24 hrs.	Iron, p.p.m.	Acid, p.p.m.	Where mine water flows
Brewster & Bilharz (1)	West		2600	8370	Willow creek to Spring river
Ebenstein (53)	West		5000-6000[1]		Willow creek to Spring river
Homestake (54)	West		5000-6000[1]		Willow creek to Spring river
Leopard (55)	West		2500-3000[1]		Willow creek to Spring river
Liza Jane (56)	West		2500-3000[1]		Willow creek to Spring river
Hartley (57)	Southwest		2000-2500[1]		7th Ave. creek (Spring creek) to Spring river
Ballard (2) St. Louis Smelting & Refining Co.	Southwest	2,800,000	1050	4100	7th Ave. creek (Spring creek) to Spring river
Opperman (4)	South	1,500,000 (estimated)	350	860	7th Ave. creek (Spring creek) to Spring river

[1] Estimated by O. W. Bilharz.

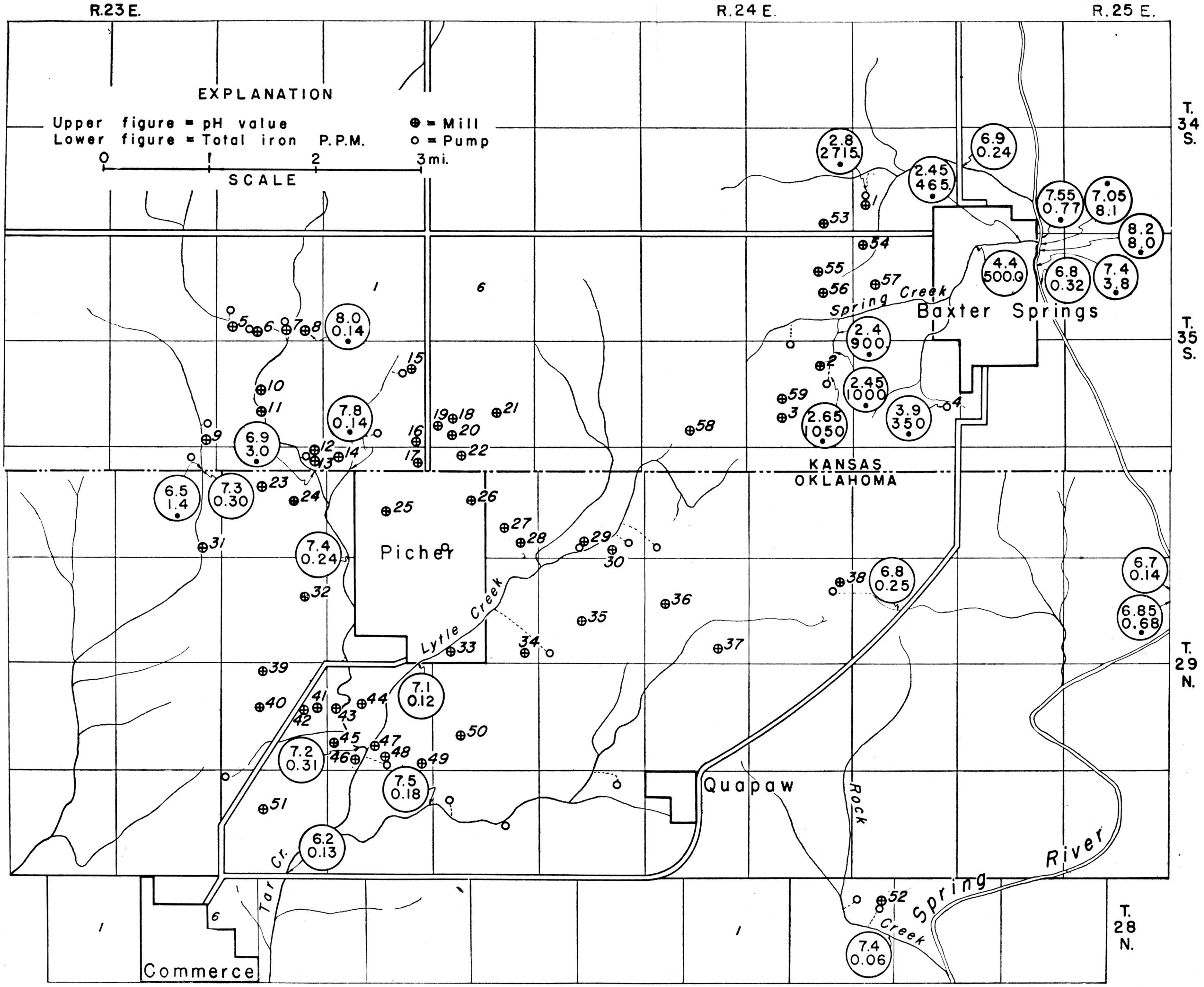

FIG. 1. Map of part of southeastern Kansas lead- and zinc-producing area, showing location of mines and sources of water samples. Numbers correspond to those in the list of mines (p. 14). Water samples indicated by dot were collected by E. D. Kinney, others were collected by the Tri-State Ore Producers' Association and the State Water and Sewage Laboratory.

The Sunflower (58 on map) (old Euterpe), Iron Mountain (3 on map), and Peru (59 on map) mines are near the extreme southwest border of this area. The water from these mines contains large amounts of iron and acid, but the mines yield only a small amount of water, which flows westward, eventually reaching Neosho river. Only the Sunflower mine is operating now and there is no mine-water problem at the present time.

When the field work for this investigation was being done, from June 16 to July 16, 1940, the Ballard mine of the Baxter Springs area was being pumped, and had been pumped for several years. Pumping from the Opperman mine started July 7, 1940, but water from this mine is not included in Table 10.

There are several variables in the problem of mine-water disposal. Both the volume of mine water in a stream and its composition can change, depending on how many and what mines are being pumped. The mines are more or less connected by underground water courses, as is shown by the fact that continuous pumping at the Ballard mine has lowered the water somewhat in other mines of the neighborhood.

Because oxygen from the air is as essential as water in forming acid and iron from pyrite, air sealing of abandoned mines and abandoned sections of active mines will reduce the acidity of the mine water considerably. That this is true has been demonstrated in the Appalachian coal fields, where the method has been employed for about eight years. The seals are constructed to permit the normal drainage of water through them, but ingress of air is prevented by forcing the water to flow through a trapped section in the seal. The principle of this arrangement is the same as that of an ordinary sink drain or sewer trap. In order that sealing will be effective, all surface openings, shafts, and tunnels leading to the section must be made as nearly air tight as it is possible to make them by ordinary construction methods.

It is estimated that if the mines were once entirely dewatered it would be necessary to pump between 2,000,000 and 3,000,000 gallons of water a day to keep them in this condition. Most of the mines have been idle for some time, however, and must be dewatered before mining can be resumed. It is estimated that steady pumping at all these mines would remove the water in three months. Such a campaign would raise the daily output of mine water by 7,000,000 gallons, to a total of 10,000,000 gallons, and place an excessive burden on any treating plant during this time. A plant for treatment of the mine water requires relatively constant feed in order to operate efficiently. Accordingly, it would be better to pump out accumulated excess mine water at a lower rate and to take more time to do it. For instance, over a period of twelve months, the extra water from this source would amount to only 1,750,000 gallons daily. This amount, added to the other 3,000,000 gallons, would make 4,750,000 gallons, an amount that could be treated readily.

The water from the Ballard mine that now reaches the river contains total iron in the amount of 465 p.p.m., and an acidity of 1540 p.p.m. This water would normally deposit about 6 tons of iron in the river each day, but about one half of the iron in the water coming from the mine is being removed along the way in settling ponds constructed by the St. Louis Smelting Company. In this system there are two shallow ponds, each several acres in extent, and shallow canals through which the mine water passes. It is reported that 1 ton of hydrated lime is added to this mine water each day. This part of the drainage is 1 mile long. The water then passes into a creek bed and without dilution finds its way to Spring river. The total distance from the Ballard mine to Spring river is about 4 miles. The following analyses show results in this settling system.

TABLE 2. *Analyses of water in Ballard mine water-treating system.*

	Acid	Iron in solution, p.p.m.	Iron separated, p.p.m.	pH
Water as discharged from mine	4100	980	70	2.65
At ½ mile, through one pond	4290	950	50	2.45
At ¾ mile, after receiving lime and passing through second pond	4220	860	40	2.40
Water as it enters the river[1]	1540	440	25	2.45

[1] This is the water utilized in our tests.

The reactions causing the iron to settle are as follows:

$$Fe_2(SO_4)_3 + 6H_2O = 2Fe(OH)_3 + 3H_2SO_4$$
$$FeSO_4 + 2H_2O = Fe(OH)_2 + H_2SO_4$$
$$2Fe(OH)_2 + H_2O + \frac{1}{2}O_2 = 2Fe(OH)_3$$

Iron hydrolyzes best in neutral solutions, the ferric iron being the more active. Iron in the ferrous condition is difficult to oxidize and precipitate. The bottoms of ponds and canals are covered with 2 to 4 inches of iron deposits.

Assuming 500 p.p.m. iron and 10,000,000 gallons of mine water a day reaching the river, the iron would amount to about 21 tons per day, or actually about twice that amount of iron hydroxide. The same amount is obtained by assuming 1000 p.p.m. of iron and 5,000,000 gallons of mine water a day. The latter figures might represent conditions if the district should have a fair increase in production, for it is to be remembered that most of the mine waters contain more iron than that from the Ballard mine. On the other hand, it might be expected that after long-standing mine water is pumped out, the water subsequently pumped would contain less iron. The greater the volume of mine water,—especially if it contains a large amount of impurities,—the greater the amount of river water that is needed to treat it, and the larger the settling capacity that is required for accumulating the iron. The mechanical features of treating so large a volume of mine water create a problem. The following analyses show how thoroughly the iron in solution has been removed after mine water reaches the river.

TABLE 3. *Precipitation of iron by water from Spring river.*

	pH	Total iron, p.p.m.	Iron in solution, p.p.m.	Acidity, p.p.m.	Alkalinity, p.p.m.
Water from Spring river	7.55	0.77	0.12		102
Ballard mine water in 7th Ave. creek, just before reaching Spring river	2.45	465.	440.	1540.	
Mouth of 7th Ave. creek (Spring river)	7.05	8.1	0.1		94
60 yards below mouth of 7th Ave. creek in Spring river	8.2	8.0	0.06		94
One-fourth mile below mouth of 7th Ave. creek	7.4	3.8	0.07		84
Three miles south, in Oklahoma	6.85	0.68	0.31		64

Seemingly, the use of any other reagent, such as limestone, would make the cost of purification far greater than if water from Spring river were used.

TABLE 4. *Comparative cost of various chemicals used in neutralizing acid and precipitating iron.*[1]

Chemical	Cost per pound, cents	Assumed purity, percent	Pounds per million gal. per p.p.m. acidity removed	Pounds per million gal. per p.p.m. iron precipitated.	Estimated cost per million gal. one p.p.m. removed	
					Acid	Iron
$Ca(OH)_2$	0.5-1.0	90	7.0	18.4	$0.035-.07	$0.138 Av.
CaO	0.5	88	5.4	14.2	0.027	0.071
$CaCO_3$ (10 mesh)	0.1	95	9.0	23.5	0.009	0.0235
Na_2CO_3	2.0	98	9.2	27.0	0.184	0.54
NaOH	2.0	100	6.8	17.9	0.136	0.34

[1] All the figures except those for iron are from U. S. Public Health Service, Office of Stream Sanitation, Cincinnati, Ohio.

TABLE 5. *Cost of crushed limestone.*

No.	Mesh	Price per ton	Price per pound	Remarks
18	18	$3.00	$0.0015	In bulk
24	24	3.00	0.0015	In bulk
200	-200	9.00	0.0045	100-lb. paper bags
200	92% = -200	7.00	0.0035	100-lb. paper bags

Quotations on limestone in car lots supplied by the Carthage Crushed Limestone Co. of Carthage, Mo., August 6, 1940.

Cost of transportation of limestone from Carthage, Mo., to Baxter Springs, Kans., is $0.75 per ton.

TABLE 6. *Example of cost of mine-water treatment with limestone.*

1 million gallons of mine water, 4100 p.p.m. acid, 1000 p.p.m. iron
Limestone 0.1 cent per pound.

Acid removal	4100 × $.009 = $36.90
Iron precipitation[1]	1000 × .0235 = 23.50
Total cost 1,000,000 gallons	$60.40[2]

[1] Assuming that the iron is in the ferric condition. Ferrous iron would not be precipitated by limestone. In neutral solution, however, it quickly oxidizes in air to the ferric state.

[2] On the basis of 10-mesh limestone at 0.1 cent per pound, a very low cost. Using limestone at 0.19 cent the cost would be $115.71.

The figures do not include the cost of unloading or feeding the limestone.

Some system of treatment of mine water is very important to the zinc-mining industry of the Baxter Springs area. The St. Louis Smelting & Refining Company, the most active producer in the district, has been the defendant in several law suits. These have been instituted by farmers, fish and game associations, and municipalities, all in Oklahoma. Spring river flows into that state a few miles below Baxter Springs. It is contended that river water contaminated by mine water is injurious to fish, livestock, and crops, and is unfit for human consumption. Most of the suits have been settled out of court. Regardless of the merits of these claims, the Kansas operators hesitate to discharge additional mine water into the river for fear of consequences. As a result, production in Kansas is lower than it normally would be if this condition did not exist. Other conditions also have a bearing on the problem.

The Empire District Electric Company operates a hydroelectric plant at Riverton, on Spring river several miles above Baxter Springs. Water is impounded behind a dam and released through turbines once a day to help generate the electric output needed to meet the peak load requirements. As a consequence, the water at Baxter Springs rises 1.5 feet in the course of an hour and stays at the new level for two or three hours. It is alleged that this sudden onrush of water scours the river bed, raising iron hydroxide that had settled. In any event, the periodic sudden increase of flow of the water does not improve the situation.

Maximum and minimum rates of flow in Spring river are important considerations in plans for the use of this water. Shoal creek is a tributary of Spring river that enters the river above Baxter Springs. Rates of flow in the two streams are as follows:

TABLE 7. *Flow of Spring river and Shoal creek.*

Spring river above Shoal creek, period April, 1924, to September, 1933:
  Maximum flow 57,400 second-feet, Aug. 17, 1927
  Minimum flow 22 second-feet, Sept. 8, 1925
Shoal creek, same period:
  Maximum flow 17,200 second-feet, Jan. 21, 1932
  Minimum flow 8 second-feet, Oct. 9, 1931

Assuming the minimum of the combined streams to be 30 second-feet: $30 \times 7.5 \times 60 \times 60 \times 24 = 19{,}444{,}000$ gallons a day. This quantity of water is sufficient to precipitate the iron from only 2,000,000 gallons of mine water, but of course the low rate of flow represented by the minimum is not normal.

Undiluted mine water from some of the zinc-lead mines in southeastern Kansas will kill fish quickly, but in the summer of 1940 no dead fish were observed in Spring river below the point where the mine water is being added. On the contrary, numerous live fish were observed. It is asserted that iron hydroxide settles on the bottom of the streams into which the mine water is emptied, destroying spawning beds of the fish.

SUGGESTED METHODS OF MINE-WATER TREATMENT

Suggested methods for settling iron hydroxide and recovering iron, discussed in following paragraphs, include (1) Settling in a slough, (2) Settling in Spring river, and (3) Settling in a Dorr Thickener, filtering the thickened pulp in a continuous filter of the drum type.

Treatment by settling in a slough.—This idea was advanced by H. H. Utley, manager of the St. Louis Smelting & Refining Company (Ballard mine). Mr. Utley has been very active in the work of mine-water disposal and has spent much time and money on the problem. Whether or not other persons and companies are co-operating financially is not known. There is a slough, 1 mile long, which parallels Spring river on the east across the river from Baxter Springs, where mine water is now discharged. An abandoned

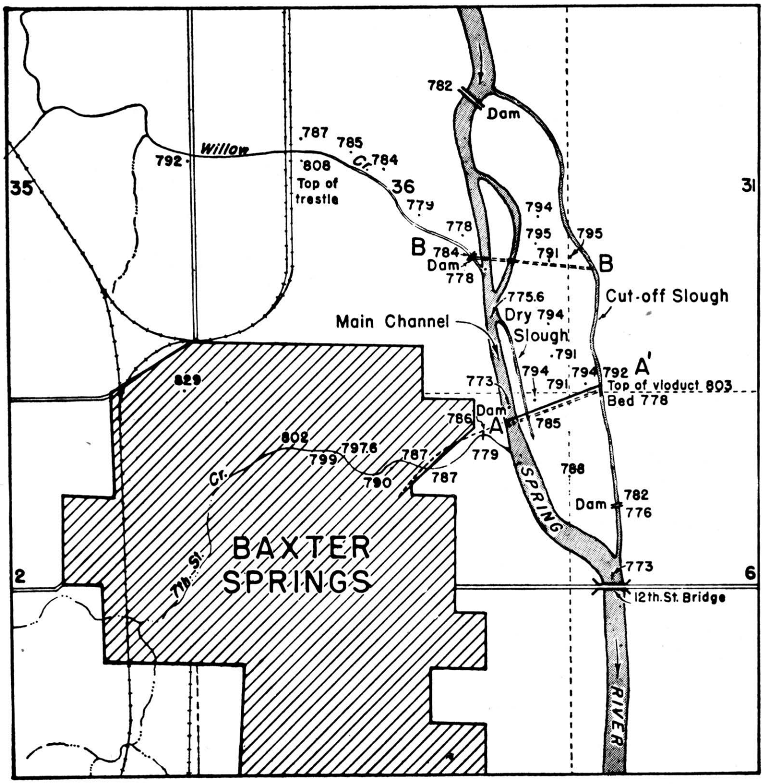

FIG. 2. Baxter Springs drainage district, showing elevations and location of profiles (fig. 3).

concrete railroad bridge crosses the river at this point. The plan involves damming the river above the mouth of Willow creek in order to force some river water into the slough. Another dam would be required at the lower end of the slough in order to control the flow where the slough enters the river. River water added to the mine water would cause the iron to be precipitated and to settle in the slough. This plan was temporarily discarded when a survey showed the bed of the slough to be higher than the river bed. The William M. Stewart Engineering Company, of Joplin, Mo., estimated the cost of the project as follows:

TABLE 8. *Estimated cost of treating mine water by settling in slough.*

Excavation, 20,000 cu. yd. at $1	$20,000
Masonry Dams, 1,500 cu. yd. at $15	22,000
Rip Rap—Retarding Dams, 1,500 cu. yd. at $10	15,000
Pipe & Wooden Conduits, 3,500 ft.	7,000
Gates, Engineering Supervision, other expenses	16,000
Total	$80,000

This plan should not be abandoned without further consideration (figures 2 and 3).

Treatment by settling in Spring river.—A later plan, also devised by Mr. Utley, involves building a dam approximately 225 feet long and 6 feet high across Spring river at a point 2 miles below the point where mine water enters, and settling the iron in

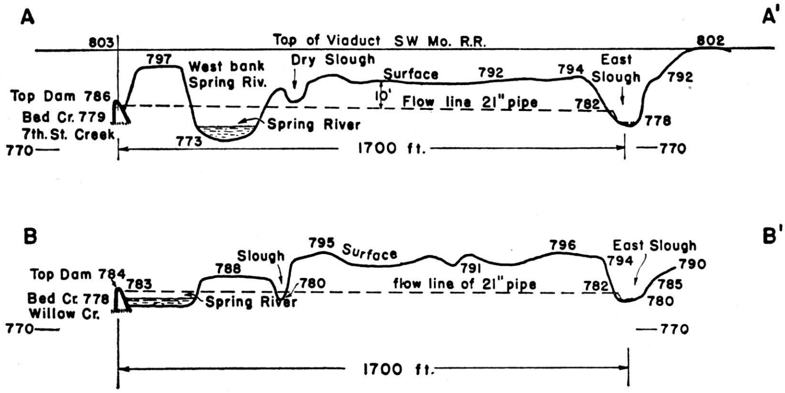

FIG. 3. Profiles through spring river and Cut-off slough east of Baxter Springs.

still water behind the dam. This plan assumes that clear water would pass over the dam under normal river conditions. Iron sludge would be pumped from behind the dam to the river bank, filtered, and prepared for market. There is some question as to just how effective this plan might be. Still water would extend for a mile behind the dam and the iron might settle over a wide area, rather than just behind the dam. Collection of iron sludge probably would not be very efficient, at least until a sizeable deposit had accumulated in the river bed, and even then the iron might be lost over the dam in times of high water. To deflect the iron precipitate so that it would settle behind the dam on the west side of the river would require construction of a 6-foot wall on the river bottom, running diagonally up the river from a point on the east side of the dam located three-fourths of the way along its length. A lift gate in the dam near the end of the east side would be necessary in order to lower the water level, without disturbing the precipitated iron, when it was desired to pump the sludge. Most of the iron would probably settle behind the dam except in periods of high water, but its recovery would very probably present difficult problems.

Treatment by thickening and filtering.—Precipitating the iron with river water in a thickener and filtering the thickened sludge on a continuous filter represents an ideal engineering method of procedure, but it involves pumping a very large volume of mine and river water,—possibly as much as 5,000,000 gallons a day of the former and 70,000,000 gallons a day of the latter. The amount of solids to be settled would be relatively small, possibly 40 tons daily, but individual particles of iron hydroxide probably require a settling period of one hour, a condition that limits the amount of feed that could be pumped without using very large units or a series of smaller units.

In answer to an inquiry, one manufacturer advises that it is perfectly feasible to run 90,000,000 gallons per day through a thickener.

It should be recalled that mine water is coming to the river now by way of 7th Avenue creek. Other mines, not operating now, discharge through Willow creek. These creeks are 0.5 mile apart at the river. If a treating plant were erected, it would be necessary to receive mine water from one stream only. It might be possible to divert the flow of Willow creek into 7th Avenue creek. There is probably enough ground available for a treating plant at the mouth of either stream.

POSSIBLE MARKET FOR RECOVERED IRON

At least one market for iron recovered from mine waters has been found close at hand. Several large portland cement plants are located in southeastern Kansas. Additional iron, over and above that occurring in the natural ingredients used in the manufacture of cement, is required by these plants in making one type of cement. The extra amount of iron is reported to be 2 percent by weight. So far as is known, there is no good source of iron available anywhere near the cement-manufacturing area. At present, pyrite cinder is being shipped to the cement plants from St. Louis. The cinder is a by-product obtained in the roasting of pyritic concentrates to obtain sulphur dioxide, which is used in the manufacture of sulphuric acid.

The possibility of revenue from the sale of iron hydroxide recovered from mine waters has not generally been appreciated by mine operators. Additional investigation is needed in order to ascertain probable demands and prices, but it now seems that the possible revenue from sale of iron precipitated from the southeastern Kansas mine waters might figure largely in offsetting the cost and maintenance of a water-treatment plant.

A plant treating 5,000,000 gallons a day of mine water containing 1,000 p.p.m. iron would produce, in 365 days, the equivalent of 10,845 tons of Fe_2O_3, if operating at 100 percent efficiency.

Following is a summary of the information obtained from some of the cement manufacturers of eastern Kansas, all using iron now, concerning the use of iron oxide: (1) The chemist of a company that is using iron oxide at the rate of about 5,000 tons annually writes, "It is my personal opinion that the A.S.T.M. type 2 cement will grow in use and that we will undoubtedly use many tons of pyrite ash or other types of iron-bearing materials in the future." (2) From an official of another company—"We use iron ore only at such times as we are manufacturing special cements for mass concrete work. Consequently the usage is restricted to the volume of this kind of business which we are able to secure and it is impossible to foretell what our requirements might be for this type of work." (3) Another letter states: "From the analysis submitted, this material (iron hydroxide from mine water) would be desirable for use in the manufacture of cement where it is necessary to increase the amount of iron oxide compounds to produce a special cement. To produce some of these will require as much as 10 pounds iron addition per barrel of cement." (4) "What is generally used is iron scale, a waste product at most of the steel roller mills, and sold at prices varying from $1.00 to $2.50 per ton. The R_2O_3 content is about 99 percent."

CONCLUSIONS

So far as the chemical aspects of this problem are concerned, it can be stated that alkaline river water has proved to be a good medium for treating the mine water. Also, considering the volume of water to be treated and the cost of other precipitants, river water seems to be the only reagent that can be employed economically for precipitating iron and reducing acidity of southeastern Kansas mine waters. Unsolved is the problem of determining what kind of reservoir or tank is best for treatment of the water and precipitation of the iron in a manner that is suited for marketing the iron.

TABLE 9. *List of Zinc-Lead Concentrating Mills.*

The numbers correspond with the numbers on figure 1.

1. Bilharz-Brewster
2. St. Louis Smelting & Refining Co.
3. Iron Mountain
4. Opperman (Mine and pump)
5. Baxter Chat Co.
6. Black Eagle
7. Federal-Muncie
8. Early Bird
9. Federal Jarrett
10. American Robinson
11. Mid Continent
12. Captain
13. Wilbur
14. Chubb
15. Kans. Ex. Jarratt
16. Webber
17. New Blue Mound
18. West Side
19. Barr
20. Youngman & Youse
21. Evans-Wallower No. 24
22. Dines Blue Mound
23. Pelican
24. Federal-Gordon
25. Tri-State Ottawa
26. Tri-State Sooner
27. Cortez
28. Andrews
29. Beck
30. Brewster
31. Bird Dog
32. Beaver
33. Cortez-New York
34. Royal
35. Atlas
36. Indian
37. Mission
38. St. Louis Smelting & Refining Co. No. 4
39. Kansas Ext. Ritz
40. Blue Goose
41. Woodchuck
42. See-Sah
43. Baird
44. Rialto
45. American Douthat
46. Cardin No. 3
47. Admirality
48. Lavrion
49. Skelton
50. Lawyers
51. Central, Eagle-Picher
52. Romo
53. Ebenstein
54. Homestake
55. Leopard
56. Liza Jane
57. Hartley
58. Sunflower
59. Peru

TABLE 10. *Analyses of water samples.*

Source	pH	Total iron, p.p.m.	Iron in solution, p.p.m.	Acidity, p.p.m.	Alkalinity, p.p.m.	District
Spring creek[1]—100 yards above mouth	2.45	465.	440.	1540.		Baxter Springs
15 feet above mouth of Spring creek in Spring river	7.55	0.77	0.12		102.	Baxter Springs
Mouth Spring creek	7.05	8.1	0.1		94.	Baxter Springs
60 yards below mouth of Spring creek in Spring river	8.2	8.0	0.06		94.	Baxter Springs
After Spring river had risen and filled Spring creek to this point. Spring creek 100 yards above mouth	3.7	25.	3.3	68.		Baxter Springs
¼ mile below Spring creek in Spring river. Above sewer	7.4	3.8	0.07		84.	Baxter Springs
3 miles south of Baxter Springs on Spring river	6.85	0.68	0.31		64.	Northeast Oklahoma
End of launder, 60 yards from mine pump, St. Louis Smelting & Refining Company	2.65	1050.0	980.	4100.		Baxter Springs (Ballard mine)
Just above lime plant, St. Louis Smelting & Refining Company	2.45	1000.	950.	4290.		Baxter Springs (Ballard mine)
¾ mile from mine, St. Louis Smelting & Refining Company	2.40	900.	860.	4220.		Baxter Springs (Ballard mine)
Opperman mine, Baxter Springs	3.9	350.	240.	860.		Baxter Springs
Brewster mine, Baxter Springs	2.8	2715.	2600.	8370.		Baxter Springs
Just below Federal Jarrett Mill, Kansas-Oklahoma line, sec. 15.	6.5	1.4	0.04		30.	Treece-Hockerville
Semple Early Bird tailings mill stream	8.0	0.14	0.04		34.	Treece-Hockerville
Just below Wilbur mill, Kansas-Oklahoma line	6.9	3.0	0.03		64.	Treece-Hockerville
Just below Chubb mill, Kansas-Oklahoma line	7.8	0.14	0.08		168.	Treece-Hockerville

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[1] Sometimes called 7th Avenue creek.

TABLE 11. *Laboratory Tests on Mine Water.*

Volume mine water[1]	Volume river water[2]	Iron Precipitation Condition after settling 45 minutes	Precipitate[3] Percent Fe_2O_3	 Percent Al_2O_3	Percent insoluble	Percent iron recovered
100	300	Very turbid	77.0	0.00	23.0	29.1
100	500	Turbid ½ settled	76.5	3.5	20.0	57.2
100	600	Turbid ¾ settled	74.1	3.9	22.0	61.7
100	700	Turbid ¾ settled	73.0	2.0	25.0	63.5
100	800	Slightly turbid 4/5 settled	75.4	0.0	24.6	70.8
100	1000	Nearly clear 9/10 settled	68.9	4.1	27.0	77.7
100	800	Slightly turbid after 6 hours	72.3	3.7	24.0	73.9
100	1500	Slightly turbid after 6 hours	58.6	9.4	32.0	84.9

[1] Filtered mine water, containing 589 p.p.m. iron.

[2] Contained 26 p.p.m. insoluble matter.

[3] Settled out after 45 minutes except as noted. Actually the precipitate contained $Fe(OH)_3$, $Al(OH)_3$, and insoluble matter. It was burned to give oxides and so weighed. Iron calculated on basis of Fe_2O_3.

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