

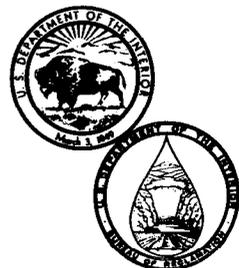
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CHARACTERIZATION OF LAVERKIN SPRINGS WATER AND METHODS FOR ITS REUSE IN ENERGY DEVELOPMENT

November 1981

Engineering and Research Center

**U.S. Department of the Interior
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16. ABSTRACT <p>Analytical water data obtained from a 9-month test program at the LVS (LaVerkin Springs) site, which is located in Washington County, Southwestern Utah, were evaluated. Fresh water and the water after processing through various pretreatment steps and after ED (electrodialysis) desalting were characterized. Upgrading water quality by various physical and chemical treatment methods and by desalting processes was demonstrated by the LVS site test program. The relative merit of different methods of treatment, disposal, and reuse of LVS water were studied. The objectives of the study were to evaluate methods for preventing high salinity LVS water from entering the Virgin River and for utilizing the processed water in energy development. The disposal of water by (1) deep well injection, (2) use as a secondary coolant in a binary cooling tower, (3) use in solar salt-gradient ponds, and (4) use as a transport media for coal slurry pipelines were found to be technically feasible. Use of LVS water to transport coal to a consuming powerplant and subsequent reuse in a binary cooling tower and/or solar salt-gradient ponds would achieve both objectives of salt reduction and energy conservation. Because LVS water has a salt content of 9500 mg/L and a boron content of 5 mg/L, it cannot be directly used for irrigation.</p>			
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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

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INTRODUCTION

The LVS (LaVerkin Springs) are highly saline springs which discharge into the Virgin River (a tributary of the Colorado River) in Washington County, southwestern Utah. The high salt content and moderate flow rates significantly contribute to the salinity of the Colorado River. Consequently, methods of preventing the salts in the water from entering the Virgin River, which flows into the Colorado River, are under study by the Bureau of Reclamation as one phase of the CRW-QIP (Colorado River Water Quality Improvement Program).

A progress report was made by the LC (Lower Colorado) Region proposing a SWCS (Saline Water Collector System) study as part of the CRW-QIP [1]*. The primary goal of the study is to assist the seven Colorado River Basin States in meeting salinity standards set for Colorado River water. The primary objective of the salinity control program and of this study is to remove 2.54×10^6 metric tons (2.8×10^6 t) of salt from the river system utilizing the most cost-effective methods. LaVerkin Springs is one of 16 identified saline water source points. LVS contributes 5 percent of the total salt reaching the Colorado River from the combined 16 point sources. The average annual water flow is $0.35 \text{ m}^3/\text{s}$ ($12.5 \text{ ft}^3/\text{s}$) or $10.24 \times 10^6 \text{ m}^3/\text{a}$ or (8300 acre-ft/yr). Since LVS has an average TDS (total dissolved solids) of 9650 mg/L, it contributes an annual salt load of 98 883 metric tons (109 000 t) and has an effect at Imperial Dam of 8 mg/L.

Although LVS contributes only 5 percent of the salt load to the Colorado river, it has been studied more than other point sources because of the accessibility of the Springs' outflows. The springs are all located along a 305 m (1000 ft) section of the Virgin River. In the area of the springs, the river channel and the springs occupy about one-fourth of the canyon floor's width. Consequently, the springflows could be separated from the river water by constructing a diversion dam in the canyon upstream from the springs. This dam would divert the flows of the river into a conduit which would convey them around the springs area. The conduit would be sized to carry all of the normal flows and most of the floodflows of the river. A control dam would be constructed immediately

* Numbers in brackets refer to entries in the Bibliography.

below the springs area to collect the spring discharges in a small pool, thus providing a forebay from which the saline water could be pumped to a chemical treatment or desalting facility.

One method studied for preventing most of the salts in the LVS water from entering the Virgin River was water pretreatment and desalination. A 9-month process study was completed at the LVS site on August 30, 1980. The objective of this process study was to chemically characterize the LVS water as it emerged from the ground and passed through the various units comprising the pretreatment and the desalting processes. These data have been assessed in this report.

Alternative methods for meeting the objective of preventing most of the LVS salts from entering the river were considered and technically evaluated in this report. The alternate methods evaluated included: (1) disposal by deep well injection, (2) use as a secondary coolant in BCT (binary cooling tower), (3) use in solar salt-gradient ponds, and (4) use as a transport media for coal slurry pipelines. A literature search of these disposal methods was made. Laboratory tests were conducted to determine the feasibility of using LVS water as a transport media for powdered coal.

CONCLUSIONS

Pretreatment and desalting processes for upgrading water quality were developed and demonstrated during a 9-month test program at the LVS site. The following characteristics were obtained for the various LVS waters:

- Fresh water from the LVS contains 750 mg/L of dissolved carbon dioxide. Typically, the water contains 400 mg/L of calcium temporary hardness and 570 mg/L of calcium and magnesium permanent hardness. Calcium carbonate precipitation will not occur if the raw water is kept under pressure in a closed system.
- About 50 percent (200 mg/L) of the calcium temporary hardness can be precipitated by air sparging the raw water or by holding the water in an open reservoir for 48 hours. The water can then be stored in open ponds without further precipitation.

- The remaining 200 mg/L of calcium temporary hardness can be removed by partial lime treatment.
- About 80 percent of the calcium-magnesium permanent hardness can be removed by following partial lime treatment with either ion exchange or soda ash treatment.
- A 90-percent water recovery by ED (electrodialysis) of pretreated LVS water containing 30 mg/L of calcium, 58 mg/L of magnesium, and 8710 mg/L of TDS was demonstrated. The ED product water contains 1370 mg/L of TDS and less than 30 mg/L of calcium and magnesium. The 10 percent of the water, which was recovered as brine, contains 94 900 mg/L of TDS, about 900 mg/L of calcium and magnesium, and is very prone to precipitation of calcium sulfate. The total quantity of salt removed was 7480 mg/L of feed water.
- High recovery desalting by either ED or RO (reverse osmosis) would require pretreatment of water by aeration, partial lime, and ion exchange or by aeration, partial lime, and soda ash.
- Based on water analysis, it is felt that lime and soda ash precipitated sludge will exceed RCRA tentative limits on radioactivity.
- Disposal of LVS water by ED or RO desalting is technically feasible.

The upgraded ED product water could be returned to the Virgin River, and the downstream river would continue to be adequate for irrigation. The waste brine could be stored in lined ponds or possibly deep well injected. Although technically feasible, a study [2] by the CRWQIP has shown that pretreatment and desalting of LVS water is not economically feasible at this time. Consequently, four alternate methods of disposing or using LVS water are under consideration by the CRWQO (Colorado River Water Quality Office). The four technically feasible disposal methods or uses include (1) deep well injection, (2) use as a secondary coolant in BCT, (3) use in solar-salt gradient ponds, and (4) transport media for coal slurry pipelines.

The following conclusions were made on alternate methods of disposal or use of LVS water:

1. Disposal of LVS water by deep well injection is technically feasible; however, further

studies (including geologic) should be undertaken. The spring water should be aerated and dual media filtered at the site to prevent postprecipitation of the calcium in solution with carbon dioxide during pipeline transport.

2. Use of LVS source water to blend with water in a conventional cooling tower or as a secondary coolant in a BCT is technically feasible. However, the raw water would require aeration, lime treatment, and dual media filtration at the site to remove temporary hardness calcium and to improve the solubility of calcium sulfate during evaporation in cooling towers. After lime softening, LVS water still contains 420 mg/L of calcium and additional ion exchange or soda ash softening might be required to satisfy cooling tower water users.
3. LVS water could be utilized as a transport media for coal slurry pipelines only after aeration to remove the calcium in solution with carbon dioxide. Use of this water as coal transport media does not significantly alter chemical composition as far as reuse potential is concerned, nor would the minor amounts of chemicals absorbed from the water by powdered coal significantly harm the coal burning equipment. However, high concentrations of salts occluded in brine waters by the coal after dewatering operations might be detrimental to the coal combustion equipment.
4. LVS water is a good candidate for use in SSGP (solar salt-gradient ponds) because of the high concentrations of sodium salts. The raw water would require aeration at the LVS site to remove calcium in solution with carbon dioxide. Additional lime/ion exchange or lime/soda ash treatment might be necessary to assure solar pond water optical clarity.
5. Studies show that the need for irrigation water in the LVS vicinity would not justify the high cost of chemical treatment and desalination of LVS waters.
6. Since implementation of any of the four alternate methods would require pipeline transfer from the LVS site to points of usage, a saline water collector system [2] would be required. Water from the springs would require aeration and filtration to prevent calcium carbonate scaling of the pipelines and pumps.

RECOMMENDATIONS

If the intended disposal or reuse of LVS water in energy development are viable options, the following additional investigations and tests are recommended:

1. Sufficient calcium carbonate sludge from aeration-lime-soda ash treatment of LVS water should be generated in the E&R Center CEPPL (chemical engineering pilot plant laboratory) to determine whether the sludge exceeds either RCRA or NRC (Nuclear Regulatory Agency) radioactivity criteria.
2. Further investigations of disposal of saline waters by deep well injection need to be pursued. The investigations should include contacts with deep well injection specialists and with the EPA (Environmental Protection Agency) and geologic studies.
3. Further investigations are needed for the applications of LVS water as blends with conventional powerplant cooling waters and as BCT secondary coolants. This phase of study requires direct contact with powerplant specialists.
4. Additional E&R Center benchscale water and coal slurry tests should be conducted. Further coal slurry tests should be made with representative composite samples of LVS water and with specific coal sources that would be transported by the test water. An investigation of the effects saline water occluded in the coal on the coal dewatering and burning equipment is required. A cooperative program with a coal burning powerplant is recommended.
5. An indepth study is needed to determine the application of LVS source waters in SSGP.

CHARACTERISTICS OF LVS WATER

The 9-month test program which was completed at the LaVerkin Springs site on August 30, 1980, was set up, operated, and deactivated by a division of Planning Research Corporation under Contract No. 7-07-30-V0001. Details of the test program are available in a two-volume document entitled "LaVerkin Springs Test Site Final Report" [6]. Summary data from the LVS site test program relevant to this report are included in table 1.

Raw Water

When LVS water is pumped from a spring well, the raw water typically contains 750 mg/L of dissolved CO₂ and has a pH near 6.0. Also, as indicated in column 4 of table 1, the raw water typically contains the following concentrations in mg/L: 820 of calcium, 150 of magnesium, 1266 of bicarbonate, 1860 of sulfate, 2220 of sodium, and 3345 of chloride. Essentially, 400 mg/L of calcium are associated with the bicarbonate as temporary hardness, and 420 mg/L of calcium are associated with chloride as permanent hardness. The raw water contains significant amounts of silica, boron, strontium, and sulfide in concentrations of 40, 5.0, 10.2, and 4.9 mg/L, respectively. All trace elements in the raw water are in concentrations of less than 0.1 mg/L. A measurable amount of radioactivity or 33 pCi/L of radium 228 is present in the water. At the bottom of table 1, the solubility of calcium sulfate in the raw water is expressed as percent water recovery; i.e., for line item 45, solubility at 20 °C is 23.0 percent. This means, when raw water is fed directly to an RO or ED process, calcium sulfate could precipitate if the process was operated at a water recovery rate greater than 23 percent. Another interpretation is that raw water should not be desalted by either ED or RO without sufficient pretreatment. Also, raw water has a high calcium carbonate scaling tendency due to dissolved CO₂.

Aerated Water

LVS's raw water before coming to the surface as a spring is under subterranean pressure. After the water comes to atmospheric pressure at the surface, CO₂ will escape from the water. Ms. Hardy [7], a Bureau engineer, performed standing water test at the LVS site to determine the amount of CO₂ that could be removed from the raw water with ponding. The test consisted of filling four 1-liter beakers with raw water and allowing the beakers to stand quiescent. Beakers were analyzed after standing 0, 24, 48, and 72 hours. The following changes occurred in the water:

	Hours			
	0	24	48	72
pH	6.2	7.3	7.5	7.6
Ca, mg/L	820	806	725	677
Free CO ₂ , mg/L	712	56	18	17

Ms. Hardy's test data showed that an aliquot of LVS raw water after standing for 24 hours would reduce in CO₂ content from 712 to 56 mg/L. After 48 hours, CO₂ reached a near-minimum level of 18 mg/L. Although at 24 hours, analysis showed 93 percent of the CO₂ escaped solution, 98 percent of the calcium was still in solution. At 48 and 72 hours, 88 and 82 percent of the calcium remained in solution, respectively. The chemical change was verified by physical observations. At 24 hours, calcium carbonate precipitate could not be observed. At 48 hours, a light coating of white precipitate was observed. At 72 hours, a markedly visible coating was seen.

During the LVS site test program, a continuous process was optimized and demonstrated for air purging CO₂ from the spring water. The characteristics of the water after thorough aeration are shown in column 5 of table 1. Aeration reduced CO₂ from 750 to 18 mg/L and raised pH from 6.0 to 7.4. At the same time, calcium was reduced from 820 to 600 mg/L (or to 73 percent) by calcium carbonate precipitation. TDS was reduced by 500 mg/L or to 9054 mg/L. No appreciable changes occurred in concentrations of magnesium, sodium, potassium, sulfate, or chloride. Aeration reduced silica from 40 to 30 mg/L, boron from 5.0 to 4.3 mg/L, strontium from 10.2 to 6.4 mg/L, and sulfide from 4.9 to 0.7 mg/L. Aeration improved the calcium sulfate solubility slightly, i.e., for line item 45 of table 1, calcium sulfate solubility increased at 20 °C from 23.0 to 37.2 percent water recovery. This indicates that after aeration, calcium sulfate would precipitate if desalting water recovery exceeded 37.2 percent.

Aerated-Lime Treated Water

During the LVS site test program, a continuous process was optimized and demonstrated for partial lime treatment of aerated water. The characteristics of LVS water after A (aeration) and subsequent partial L (lime) treatment are summarized in column 6 of table 1. Subsequent partial L treatment to an adjusted pH of 9.5 removed the rest of the calcium temporary hardness from solution by precipitation as calcium carbonate. Permanent calcium hardness remained at a level of 420 mg/L. The A-L treatment removed 49 percent of the calcium from solution. The A-L treatment also changed water characteristics by reducing the concentrations in mg/L of silica from 40 to 15, magnesium from 150 to 128, bicarbonate from

1266 to ND (not detectable), strontium from 10.2 to 4.7, and sulfide from 4.9 to ND. TDS was reduced from 9507 to 8530 mg/L. As indicated by line item 45 of table 1, precipitation of calcium sulfate is not likely since the percent water recovery possible before calcium sulfate precipitation occurs is 49.9 percent at 20 °C. However, A-L pretreatment does not produce sufficiently softened feed water for high recovery ED or RO desalting.

Aerated-Lime-Ion Exchange Treated Water

Following removals of temporary calcium hardness by aeration and lime treatment, a process was optimized and demonstrated for IX (ion exchange) treatment. The characteristics of LVS water after A-L-IX treatment are summarized in column 7 of table 1. Before IX treatment, pH was adjusted to 7.5 with sulfuric acid. Sodium-calcium ion interchange is very effective in removing permanent hardness. Calcium was reduced from 420 to 30 mg/L and magnesium was reduced from 128 to 58 mg/L. The IX did not significantly affect the concentration of silica or boron, but reduced strontium from 4.7 to 0.4 mg/L. The TDS increase from 8530 to 8710 mg/L was primarily due to divalent calcium exchange by monovalent sodium. The calcium sulfate precipitation tendency of A-L-IX treated water is essentially nil as indicated by line item 45 of table 1. At 20 °C, 92 percent of the water could be removed from the treated solution before any calcium sulfate would precipitate. The A-L-IX pretreated water is acceptable as feed for high recovery ED or RO desalting.

Aerated-Lime-Soda Ash Treated Water

One of the objectives of the LVS site test program was to compare continuous IX treatment with continuous SA (soda ash) treatment for removal of calcium permanent hardness. During the LVS site test program, a continuous process was optimized and demonstrated for SA treatment of A-L treated water. The characteristics of IX treated water compared with SA treated water are shown in columns 7 and 8 of table 1. The IX treatment reduced calcium to 30 mg/L, and SA treatment reduced calcium to 60 mg/L. Also, IX treatment reduced magnesium to 58 mg/L and SA treatment reduced magnesium to 93 mg/L. Neither treatment had a significant effect on silica or boron. The IX treatment reduced strontium to 0.4 compared to 1.0 for SA. The A-L-SA treatment reduced radium 226 from 33 to 1.5 pCi/L. The total

Table 1.— Characteristics of LVS water through various stages of processing

(1) Item	(2) Characteristic	(3) Units	(4) Raw water (R) ¹	(5) Aerated water (A) ²	(6) Lime-treated water (A-L) ³	(7) Lime-ion exchange (A-L-IX) ⁴	(8) Lime-soda-ash treated (A-L-SA) ⁵	(9) Lime-soda-ash IX treat (A-L-SA-IX) ⁶	(10) (11) Electrodialysis (90 percent water recovery)		(12) (13) Effects of coal on water		(15) Item	
									(10) Product (ED-P) ⁷	(11) Brine (ED-B) ⁸	Before	After		
1	pH	—	6.0	7.4	9.5	7.5	10.2	7.6	7.4	7.7	7.6	8.1	1	
2	TDS* (calculated)	mg/L	9243	8754	8430	8930	8282	8627	1370	91 900			2	
3	TDS (evaporated at 105 °C)		9507	9054	8530	8710	9062	8620	1370	94 900	9190	8940	3	
4	Conductivity at 25 °C	mS/L	1480	1410	1280	1320	1380	1450	264	8 590	1410	1340	4	
Major Constituents														
5	Silica	mg/L	40	30	15	15	2	2	6	8	29	28	5	
6	Calcium	mg/L	820	600	420	30	60	6	6	366	502	338	6	
7	Magnesium	mg/L	150	144	128	58	93	46	20	557	144	100	7	
8	Sodium	mg/L	2220	2220	2300	2970	2690	2970	460	32 100	2330	2510	8	
9	Potassium	mg/L	182	181	180	153	188	153	23	2 650	173	117	9	
10	Bicarbonate	mg/L	1266	795	ND	46	ND	10	20	83	868	482	10	
11	Carbonate	mg/L	ND	ND	26	0	43	ND	0	0	60	0	11	
12	Sulfate	mg/L	1860	1850	1850	1970	1970	1970	181	22 200	1840	2060	12	
13	Chloride	mg/L	3345	3330	3340	3340	3350	3390	653	36 400	3230	3410	13	
14	¹⁰ T-alkalinity as CaCO ₃	mg/L	1038	652	50	38	70	8					14	
15	¹¹ P-alkalinity as CaCO ₃	mg/L	ND	ND	30	0	34	ND					15	
16	Free carbon dioxide	mg/L	750	18	ND	0	ND				0	0	16	
17	¹² E.F. [TDS (calculated)/cond.]		6.2	6.2	6.2	6.8	6.0		5.2	11.0			17	
18	E.F. [TDS (evaporated)/cond.]		6.4	6.4	6.3	6.6	6.6		5.2	11.0			18	
19	Σ Anions	meq/L	153.9	145.4	133.3	142.2	134.5	138.8	22.5				19	
20	Σ Cations	meq/L	153.6	143.1	131.0	143.0	132.7	137.2	22.5				20	
Trace Elements														
RCRA ¹³														
21	Arsenic	mg/L	5.0	0.1							0.1	< 0.1	21	
22	Barium	mg/L	100.0	0.09							0.09	0.05	22	
23	Boron	mg/L		5.0	4.3		4.1	4.2	3.5	2.9	5.0	6.2	23	
24	Cadmium	mg/L	1.0	0.004							0.0012	0.0035	24	
25	Chromium	mg/L	5.0	0.002									25	
26	Iron	mg/L		< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	0.9	0.08	< 0.04	26	
27	Lead	mg/L	5.0	0.012							0.012	0.011	27	
28	Mercury	mg/L	0.2	0.0038						0.0055			28	
29	Manganese	mg/L		0.013							0.04	0.03	29	
30	Selenium	mg/L	1.0	< 0.02							< 0.1	< 0.1	30	
31	Silver	mg/L	5.0	< 0.0005							< 0.0005	< 0.0005	31	
32	Aluminum	mg/L		< 0.1									32	
33	Copper	mg/L		0.001							0.004	0.27	33	
34	Nickel	mg/L		0.01							< 0.02	0.03	34	
35	Zinc	mg/L		< 0.1							0.06	0.005	35	
36	Strontium	mg/L		10.2	6.4	4.7	0.4	1.0	< 0.3	< 0.1	4.0	9.0	36	
37	Sulfide	mg/L		4.9	0.7	ND		ND		ND			37	
Trace Anions														
38	Orthophosphate	mg/L		2.6			0.6						38	
39	Nitrate	mg/L		1.8									39	
40	Fluoride	mg/L		2.6									40	
41	Total organic carbon	mg/L									2	8	41	
Radioactivity														
42	Radium 226	pCi/L	¹⁴ 5.0	33.3				1.5		0.0	2.5		42	
43	Radium 228	pCi/L		0									43	
Desalting-% Water Recovery														
Based on CaSO ₄ solubility at														
44	0 °C	%		4.3	21.9	38.0	91.6	86.8	96.7	99.0	11.8	21.9	47.1	44
45	20 °C	%		23.0	37.2	49.9	92.0	88.2	96.6	99.1	15.4	37.2	61.8	45
46	50 °C	%		28.2	41.6	53.5	92.4	88.9	96.8	99.1	19.7	41.6	66.3	46
47	90 °C	%		16.1	31.7	45.6	92.2	87.9	97.0	99.1	15.2	31.7	56.5	47

¹(R) — Raw water

²(A) — Aerated water

³(A-L) — Aerated-lime treated water

⁴(A-L-IX) — Aerated-lime-ion exchange treated water

⁵(A-L-SA) — Aerated-lime-soda ash treated water

⁶(A-L-SA-IX) — Aerated-lime-soda ash-ion exchange treated water

⁷ED-P — Electrodialysis-product

⁸ED-B — Electrodialysis-brine

⁹TDS — Total dissolved solids

¹⁰T — Total alkalinity

¹¹P — Phenolphthalein end point

¹²E.F. — Effluent Filtrate

¹³RCRA — Resources Conservation Recovery Act

¹⁴5 pCi/gm

hardness of both IX and SA treated water is sufficiently reduced for use as feed water in a desalting process.

Aerated-Lime-Soda Ash-Ion Exchange (Polished) Treated Water

Characteristics of A-L-SA-IX treated water were also determined during the LVS site test program. Polishing with IX essentially removed all silica, calcium, and strontium as indicated by column 9 of table 1.

Electrodialysis Desalted Water

An objective of the LVS site test program was to optimize and demonstrate an electrodialysis desalting process. The characteristics of ED-P (electrodialysis product) water at 90 percent water recovery are shown in column 10 of table 1. Characteristics of the ED-B (electrodialysis brine) are shown in column 11. The feed water used for ED desalting was A-L-IX pretreated. TDS in the ED-P was 1370 mg/L and in the ED-B was 94 900 mg/L. About 88 weight percent of the calcium and about 76 weight percent of the magnesium ended up in the brine. Boron ended up in nearly equal concentrations in the product water and brine. All the remaining radium 226 ended up in the brine. Compared with the raw water and the aerated water, the ED-B has a higher tendency to precipitate calcium sulfate. Referring to line item 45 of table 1, if the ED-B were to pass through another desalting step, calcium sulfate would precipitate when water recovery exceeded 15.4 percent. Another interpretation would indicate calcium sulfate precipitation will occur in a brine pond when more than 15.4 percent of the water evaporates.

ALTERNATE METHODS OF WATER DISPOSAL

All alternate methods require the pumping of water from the LVS site using a large pipe network or collector system. The collector system would permit disposal of LVS water by deep well injection at some remote location so that it would not enter the Virgin River or for other alternate uses such as water for coal slurry pipeline transport, water for cooling towers at steam generating powerplants, and water for solar salt-gradient ponds.

Saline Water Collector System

The Interior Dept., Office of Water Research and Technology has extensive corrosion studies of construction materials for transport of saline water by pipeline and for desalting plant equipment [10]. A list of acceptable construction materials for a saline water collector system has been compiled in table 2. Established technology is available for pipeline transfer of saline waters similar to those which might be transported from LVS. No unusual construction problems are evident.

The high CO₂ content in LVS raw water could create a CaCO₃ (calcium carbonate) postprecipitation problem in a saline water collector system. LVS water contains about 750 mg/L of dissolved CO₂. If the CO₂ is allowed to come out of solution, about 25 percent of the calcium present in the raw water will precipitate. The mechanism of precipitation is for nucleation to occur on process equipment wetted surfaces. A hard, tenacious scale builds up on all internal wetted surfaces. If the raw water could be retained under pressure during the time it is drawn from the springs and transferred into the high-pressure collector pipeline, calcium carbonate scaling would not take place. If the raw water could be maintained under pressure until mixed with coal in a water-coal slurry pipeline, sufficient softening will occur so that subsequent release of pressure will not pose a scaling problem. The scaling tendencies for untreated or treated waters are discussed in the "Characteristics of LVS Water" section of this report.

Maintaining raw water from the springs under pressure may not be practical and several other methods of collecting the LVS water have been suggested. The method that is probably the best would be to collect spring water in a reservoir prior to transfer to a collector pipeline system. The reservoir would need to provide sufficient residence time to permit CO₂ to escape and calcium carbonate to precipitate. Effluent from the reservoir would need filtration before transferring to the collector system. A second method which would avoid the need for a large reservoir would be to build a partial pretreatment plant at the LVS site. The pretreatment would include aeration, clarification, and filtration. These simple pretreatment processes could be fully automated for unattended continuous operation.

Table 2.—Construction materials for handling LVS water

Material	Satisfactory for		
	> 410-mm (> 16-in) pipeline	Deep well injection	Binary cooling tower (BCT)
RPM (reinforced plastic mortar) pipe	X		
PVC (polyvinyl chloride) pipe	X		
PE (polyethylene) pipe	X		
RTR (reinforced thermalsetting resin pipe)	X		
70-30 copper-nickel pipe	X	X	
90-10 copper-nickel pipe	X	X	
Aluminum bronze pipe	X		
Asbestos cement pipe	X		
Mylar			X
Type V cement plus good pozzolan		X	X
Concrete with reinforcement steel	X	X	X
316L Stainless steel	X	X	X
PVC- and PE-lined or -coated steel pipe	X	X	X
Corrosion-resistant cements		X	X
Silicone bronze			X
Wood			X
Polymer-coated steel			X

Other methods for collecting the springs have been suggested. Among these are: (1) use of common underground collection chamber by constructing a completely enclosed underground chamber to collect water from all the individual springs does not appear practical, and (2) drill a well for pumping out each of the springs. Since numerous springs are involved, the cost of individual wells would probably be prohibitive.

Deep Well Injection of LVS Water

Deep well injection of LVS water will probably be permitted under EPA and UIC (Underground Injection Control) regulations. The UIC rules regulate the deep well injection of industrial and municipal waste, oil and gas drilling brines, waste from mining and energy operations, hazardous waste, and all others. Compared with most waste already regulated by UIC, LVS waters are clean, innocuous, and natural. Health spas have used this water for many years. Deep well injection of brines has been commonplace in the oil drilling industry for many years and injection equipment has been well established. Table 2 lists some of the construction materials which are satisfactory for use in brine injection wells.

Any precipitation of calcium carbonate or sulfate after injection can result in plugging of the injection zone and a slowing of the permissible rate of injection. To prevent postprecipitation of calcium an aeration, clarification, and filtration pretreatment is required. Postprecipitation could also be prevented by adding sulfuric acid to reduce pH just prior to deep well injection.

The limits of solubility of divalent salts and silica in LVS water were calculated either from solubility product, temperature concentration relationship, or computer Marshall Program [9]. These solubilities are shown in column 3 of table 3. The maximum calculated solubilities in LVS raw water are shown in columns 5 and 6, respectively. These data further indicate that barium, calcium, magnesium, silica, and strontium compounds are not likely to precipitate during deep well injection.

Use of LVS Water as a Transport Medium for Coal Slurries in Pipelines

The effects of powdered coal on saline water were determined by a literature search and by coal slurry test conducted in the chemical engineering benchscale laboratory.

Table 3.—Solubility of barium, calcium, magnesium, silica, and strontium compounds

(1) Compound material	(2) Formula	(3) Literature ¹ solubility product, K_{sp} (moles/L)	(4) (5) (6) Solubility of cation		
			(4) Type (mg/L)	(5) Max. calculated from col. 3 (mg/L)	(6) In LVS water (mg/L)
Barium sulfate	BaSO ₄	1.1×10^{-10}	Ba ⁺²	0.01	² ND
Calcium carbonate	CaCO ₃				³ 0
Calcium sulfate	CaSO ₄	Marshall Program ⁵	CaSO ₄	10 200	2750
Magnesium hydroxide	Mg(OH) ₂	1.2×10^{-11}	Mg ⁺²	489	144
Silica	SiO ₂	⁴	SiO ₂	147	40
Strontium carbonate	SrCO ₃				³ 0
Strontium sulfate	SrSO ₄	8.75×10^{-5}	Sr ⁺²	17	11

¹ 34 °C reference temperature.

² Not detectable (below detectable limit).

³ There are no detectable carbonate ions in LVS water, since all carbonates are present in the bicarbonate form.

⁴ [(37.3 mg/L or solubility of silica at 0 °C) + (34 °C – 0 °C)(342 mg/L or solubility at 1 °C)].

⁵ Marshall Program [9]

Utah Water Research Laboratory Coal Slurry Program.—A study has been completed at UWRL (Utah Water Research Laboratory) by Israelsen, et al. [3], of Utah State University on the use of saline water in energy development in the semiarid regions of the intermountain west. The report details the use of saline water as a transport medium for coal slurries in pipelines. Experimental data were obtained by adding 150 g of powdered coal to 150 mL of the test water into a 500-mL Erlenmeyer flask. Slurry flasks were fastened securely to an orbit shaker table and vibrated at approximately 200 r/min for 6 days to simulate the pipeline pumping of coal and water slurry. After completing each slurry test, water was recovered from the coal by gravity filtration. Analyses were made of the initial water and final filtrate water. If the final filtrate water showed a higher concentration amount of any chemical ions than was in the initial test water, desorption from the coal particles was assumed. Conversely a reduction in the concentration of a chemical ions in the filtrate indicated adsorption by the coal particles.

The UWRL coal slurry study tested four different sources of coal and three different sources of saline ground water. Ground waters containing 2220 mg/L, 4640 mg/L, and 13 200 mg/L of TDS were tested. Each combination of coal and ground water was tested 10 times. For each test

replicate, initial water and final filtrate water were analyzed in triplicate for dissolved chemical ions. A statistical average value for each chemical ion was reported with a 99.0 percent degree of confidence. The UWRL study found that some chemical constituents such as boron, strontium, organic carbon, and sodium were leached from the coal. Other chemical ions such as phosphorus, silica, calcium, and magnesium were removed by the coal. Again, other constituents such as aluminum, chloride, fluoride, manganese, and sulfate were not significantly changed. The UWRL study also checked for changes in many trace elements. All of these trace elements were at levels less than 0.1 mg/L in both the initial and final extract water. Since these ions were at the lower analytical detectable limits, no conclusions could be made as to what degree trace elements are adsorbed or desorbed from the coal.

The UWRL study tested saline ground waters with 4640 mg/L and 13 200 mg/L of TDS. These water concentrations bracket the 9480-mg/L TDS content of LVS water. Table 4 compares LVS water before and after slurrying with powdered coal. Table 4 data assumes that LVS water would react with powdered coal similarly to the 4640-mg/L TDS water in the UWRL study. The data indicate slurrying LVS water with coal would have a beneficial softening effect on the water. In the UWRL tests, the water after contact with coal

Table 4.—Estimated changes in constituents after slurring one part of LVS water with one part of powdered coal (based on UWRL study)

Constituent	Before	After	Percent change
	(mg/L)		
Calcium	880	827	- 6
Magnesium	139	115	- 17
Sodium	2250	2330	4
Potassium	195	193	- 1
Sulfate	1900	2080	9
Chloride	3270	3330	2
Silica	40	28	- 30
Boron	6	8	33
Strontium	11	15	36
Each and all trace elements	< 1	< 1	0
Organic carbon	2	29	1400

had lower quantities of calcium, magnesium, and silica. Conversely, the filtrate water increased in sodium chloride and sulfate salts. Since the raw LVS water contains 7420 mg/L of sodium salts, the slight increase to 7740 mg/L in the filtrate would not in itself have a significant detrimental effect on the end use of the water in BCT. The UWRL data indicate LVS water may leach some boron, strontium, and organic matter from the powdered coal. Here again, the slight increase in the leached materials in the water would not seriously affect its reuse as BCT water, but could be detrimental to reuse as water for agriculture. However, LVS water could be acceptable for irrigation after A-L-IX or A-L-SA softening and desalination to reduce TDS to an acceptable level. As discussed later, boron cannot be completely removed by pretreatment and desalination. Dilution with low boron waters could permit use of the LVS water for irrigation.

Engineering and Research Center LVS Water and Coal Slurry Test.—Coal slurry and LVS water tests were made using a coal from the Jim Bridger Coal Mine, Rock Springs, Wyoming. Typical analyses for Jim Bridger coal are shown in appendix A. The coal sample was prepared by pulverizing the coal to pass through a 75 μm (No. 200) screen. The apparatus, similar to that used at Utah State University, was employed by the Division of Research in conducting this water and coal slurry test. Aliquots of 300 mL of test water and 300 grams of powdered coal were charged to each 500-mL Erlenmeyer flask. After installing a

rubber stopper, the test mix occupied about 90 percent of the flask. For each water test, three 500-mL flasks were charged. Flasks were mounted in a tumbler rack. Two test water samples or six flasks were mounted for each operation of the tumbler. Flasks were then set to tumble 5 days or 120 hours bottom over top over bottom at the rate of 25 times per minute. Tumble speed was controlled by a Boston Gear Rotitrol powered by a 125-W (1/6-hp) motor. After completion of each tumble operation, water was removed from the coal by gravity filtration through No. 1, 24.0-cm filter paper. Water from the three flasks for each test water was combined to obtain a sufficient quantity for analysis. Analyses of the LVS water before and after the coal slurry test are summarized under column 9 and 10 of table 1.

The significant changes that were observed in the concentrations of LVS water constituents before and after slurring with powdered coal are shown in table 5. Specific trace metals were not carried over from table 1 because the concentrations of trace metals in the water before and after the coal slurry test were at concentrations of less than 0.1 mg/L. Generally, the data in table 5 indicate the quality of LVS is improved after using it as a coal transport. About 30 percent of the calcium and magnesium hardness is removed from the water by powdered coal. This agrees with the predictions shown in table 4, where the effects of powdered coal on LVS water were estimated based on the UWRL data. In fact, all data in table 4

agree with data in table 5 as far as the plus or minus direction of the percent change. The concentrations of silica, potassium, bicarbonate, CO₂, and net TDS decreased. The decrease in silica, bicarbonate, and CO₂ is probably related to the calcium and magnesium softening. The 32.4-percent decrease in potassium is more difficult to explain. It is suspected that the coal might function like an ion exchange resin. The potassium has a lower charge to weight ratio than the sodium ion. A potassium-sodium exchange could occur at the coal surfaces. There was a net increase of sodium, sulfate, chloride, boron, strontium, and total organic carbon in the water. Some of the sodium might have washed from the coal as chloride or sulfate salt. Some of the sodium might have exchanged from the coal to the water with calcium, magnesium, or potassium. Because of the predominant organic nature of coal, an increase in the total organic carbon dissolved in the water is to be expected.

LVS water, untreated or treated, had a sulfate content near 1900 mg/L. High sulfate would not be detrimental to the coal. Alkaline sulfate salts in the water occluded by the powdered coal could have a beneficial affect on burning the coal in a powerplant. A recent process study made by the Research Division at Southern Company Services [4] (Birmingham, Ala.) found the addition of sodium sulfate salt to raw coal before feeding to a

furnace to be beneficial. They add 0.24 kg (0.52 lbs) of sodium sulfate per 45.4 kg (100 lbs) of raw coal before feeding it into the furnace. Using this method, they operated a unit at Gulf Power (Panama City, Fla.) for over 6 months without a shutdown for precipitator cleaning. Previously, the company shut down for maintenance every 6 to 8 weeks. Southern developed the method after tests of the ash layer that collects on "hot side" precipitator plates showed there was not enough sodium oxide to maintain an ideal electrical field.

Use of LVS Water for Powerplant Binary Cooling Towers

The report "Use of Saline Water in Energy Development" by UWRL [3] also determined the feasibility of using saline water in BCT's. The BCT process utilizes a heat exchange system designed such that air and low-quality water can be circulated through the evaporative secondary loop as shown on figure 1.

Very high salinities can be tolerated in the secondary loop by use of corrosion resistant materials together with feed and side stream softening to prevent scaling. Heat exchanger detail is shown on figure 2. The heat exchanger panels are composed of plastic framing materials, plastic water manifolds, and Mylar sheets. Effective heat

Table 5.—Actual changes in constituents after slurring one part of LVS water with one part of powdered coal

Constituent	Quantity			Percent change
	Before	After	Change	
	(mg/L)			
TDS	9190	8940	250	-2.7
Silica	29	28	1	-3.0
Calcium	502	338	164	-32.7
Magnesium	144	100	44	-30.6
Sodium	2330	2510	180	7.7
Potassium	173	117	56	-32.4
Bicarbonate	868	482	386	-44.5
Carbon dioxide	60	0	60	-100.0
Sulfate	1840	2060	220	12.0
Chloride	3230	3410	190	5.9
Boron	5.0	6.2	1.2	24.0
Strontium	9.0	—	—	—
TOC (total organic carbon)	2	8	6	300.0
Each and all trace elements	<0.1	<0.1	0	0

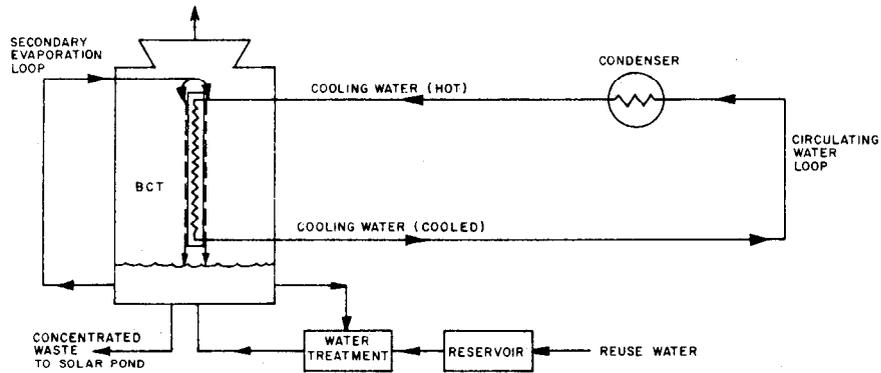


Figure 1. - BCT system flow diagram.

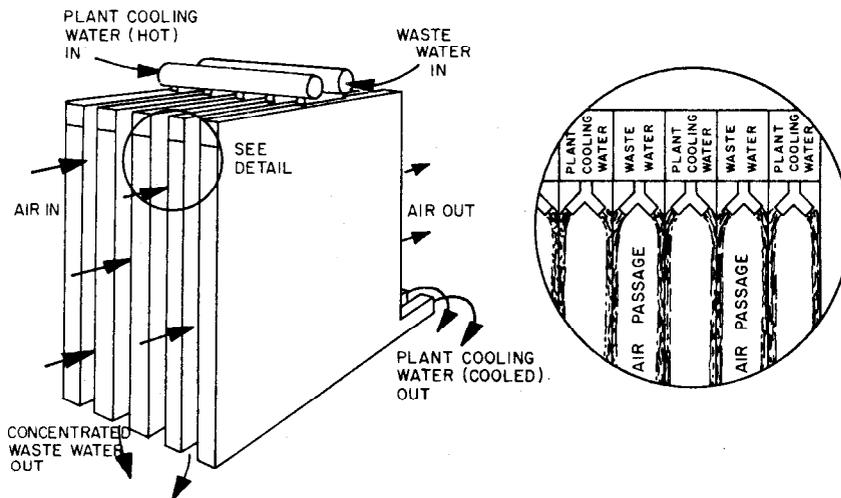


Figure 2. - BCT heat exchanger detail.

transfer rates are achieved through the Mylar sheets in spite of their relatively low thermal conductivity due to the thinness of the sheeting and the falling film configuration of the primary cooling water on one side and the high salinity evaporating loop water on the other.

The BCT system was successfully tested over an 11-week period (March–June 1979) at the Nevada Power Company’s Sunrise Station at Las Vegas. The results of that test (Slate et al., 1979 [5]) were impressive. The system operated satisfactorily with secondary evaporation loop TDS levels of 80 000 to 130 000 mg/L. The

magnesium, calcium, and silica levels were controlled by softening of the makeup water and side stream treatments to ensure the sum of the concentrations of magnesium, calcium, and silica did not exceed 400 mg/L. The report concluded that BCT systems using saline makeup water (such as LVS waters) are technologically feasible.

Column 12 and 13 of table 1 show that the LVS raw and coal contacted water would need to be softened in order to obtain the salinities indicated in the Nevada Power Company test. The A-L-IX or A-L-SA pretreatments could achieve the desired degree of softening.

Use of LVS Water in Solar Salt-Gradient Ponds

In a study of Dixit [8], characteristics of saline waters used for construction and maintenance of SSGP were discussed. Candidate saline waters should possess salt with adequate solubilities to prevent precipitation at increased temperatures and should be relatively transparent to solar radiation. Dilute saline water entering at the upper surface of a pond should be free of suspended matter, lack color, and remain clear. The bottom layer of the pond is maintained at a concentration of 260 000 mg/L by evaporation of sidestreams of SSGP feed water in auxiliary evaporation ponds or in cooling towers.

According to Dixit, some precipitation could occur in the SSGP's bottom layer without long-term loss of clarity. This assumes precipitated particles would settle on the pond bottom. However, to assure LVS water does not become turbid because of post precipitation of calcium carbonate or sulfate precipitation, some pretreatment would be required. The minimum treatment would be aeration to remove the calcium in solution with dissolved carbon dioxide and dual media filtration to remove suspended solids. Line item 47 of column 5 of table 1, indicates that calcium sulfate will precipitate from aerated water if evaporation exceeds 31.7 percent. It would need to be evaluated experimentally to determine whether additional pretreatment is needed to prevent SSGP turbidity. Lime treatment (see col. 6, table 1) would be required to remove the remaining calcium carbonate and permit 50 percent evaporation before calcium sulfate precipitates. Further IX softening (column 7) would permit 92 percent evaporation or further SA softening (column 8) would permit 88 percent evaporation.

Use of LVS Water for Irrigation

LVS water to be acceptable for irrigation must be chemically pretreated and processed through either RO or ED desalination. Studies by Israelsen et al. [3], have shown that the need for irrigation water in the LVS vicinity would not justify the high cost of chemical pretreatment and desalination.

The high boron content of the LVS water would also be a concern if it is to be used for irrigation. Boron is essential in small quantities for plant nutrition but toxicity is evident at higher concentrations. Sensitive, semitolerant, and tolerant crops would show boron injury if the irrigation

water used over a prolonged period contained levels of boron from 0.3 to 1.0 mg/L, 1.0 to 2.0 mg/L, and 2.0 to 4.0 mg/L, respectively. The EPA (1976) recommends a boron concentration not to exceed 0.75 mg/L for long-term irrigation.

The effects of pretreatment and desalting on the boron content of LVS water are shown in table 6. As seen, even the RO product exceeds the EPA standard of 0.75 mg/L. Processing the LVS water through chemical pretreatment, IX, RO, and ED does not appreciably reduce the boron content.

Table 6.—*Boron content of pretreated and desalted LVS water*

Description	Boron (mg/L)
R (raw) spring water	5.0
A (aerated spring water)	4.3
R, A, L-SA (lime-soda ash) treated water	4.2
R, A, L-SA, ED: product water	3.5
brine	2.9
R, A, L-SA, IX treated water	4.1
R, A, L-SA, IX, RO: product water	3.2
brine	5.0

RCRA (Resource Conservation and Recovery Act) Considerations

If LVS raw water is processed at the site, considerations should be given to generation and storage of hazardous waste under the RCRA regulations. Process brines and sludges from a natural brine water such as LVS water needs to be assessed for characteristics of heavy metal content, toxic organic compounds, radioactivity, and corrosivity. The RCRA maximum criteria for hazardous waste classification are compared in table 7 with pollutants that would be present in LVS pretreatment sludges and brines. If raw water were treated with lime (calcium hydroxide) and soda ash (sodium carbonate) to reduce its potential for fouling, 3.4 parts of dewatered (60 percent solids) calcium carbonate sludge would result from every 1000 parts of raw water processed. Any toxic metals in LVS raw water would concentrate 1000/3.4 or 333 times in the calcium carbonate sludge. The EP (extractable product) toxicity limits in column 2 (table 7) are for a 20 to 1 water extract of a solid waste. Therefore, column 3 (table 7) for EP toxicity was derived by multiplying the trace elements in column 4 (table

Table 7.—Comparison of LVS sludge and brine pollutants with RCRA maximum limits

(1)	(2) RCRA hazardous waste criteria 20:1 extract	(3) Pretreatment sludge 20:1 extract	(4) Desalting brine 90% recovery
EP INORGANIC TOXICITY (max. conc.), mg/L			
Arsenic	5.0	1.7	1.0
Barium	100.0	0.2	0.9
Cadmium	1.0	0.007	0.04
Chromium	5.0	0.004	0.02
Lead	5.0	0.2	0.12
Mercury	0.2	0.06	0.04
Selenium	1.0	< 0.3	0.2
Silver	5.0	< 0.008	0.005
CORROSIVITY**	> 6.35 mm/a (> 0.250 in/yr)	*	1.04 mm/a (0.041 in/yr)
RADIOACTIVITY			
Radium 226 and 228, pCi/gm of solid	< 5	10	0.005

* Sludge is not expected to be corrosive.

** Liquids are corrosive if they corrode steel (SAE 1020) at a rate greater than 6.35 mm/a (0.250 in/yr) at test temperature of 50 °C (130 °F) as determined by test methods specified by NACE (National Association of Corrosion Engineers) Standard TM-01-69.

1) by 333/20 or 16.7. Column 3 (table 7) assumes the worst condition of all toxic metals in the raw water ending up in the sludge. All the metals in the sludge are well below RCRA limits.

Also, column 4 (table 7) was derived assuming the worst condition that all the toxic metals would end up in the brine from the 90-percent water recovery desalting operation. The values in column 4 were derived by multiplying values in column 4 (table 1) by 10. All metals in the brine are well below RCRA limits.

The maximum corrosivity allowed by RCRA regulations is 6.4 mm/a (0.25 in/yr). A brine recovered while operating the ED cell at 90 per-

cent water recovery was tested. LVS brine gave a 1.04 mm/a (0.041 in/yr) corrosion rate.

The RCRA tentative limit shown in column 2 (table 7) (as radium 226 and 228) is 5 pCi/gm of solid. A sample of LVS water was found to contain 33.3 pCi/L of raw water. As previously indicated, lime treatment would produce 3.4 g of 60 percent sludge from a liter of raw water. Assuming the worst condition that all radioactivity concentrates in the sludge, the radioactivity in the sludge would be 33.3/3.4 or 10 pCi/gm. This would indicate that calcium carbonate sludges obtained from aeration and lime treatment of LVS would need to be handled and stored according to RCRA regulations.

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APPENDIX A Typical Analysis for Jim Bridger Coal

CABLE ADDRESS COMTECO

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 328 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 728-8434

EASE ADDRESS ALL CORRESPONDENCE TO:
10775 EAST 5TH AVE., DENVER, COLO. 80239



OFFICE TEL (303) 373-4772

▶ PACIFIC POWER & LIGHT COMPANY
920 S. W. 6th Ave.
Portland, Oregon 97204

January 25, 1978

Sample Identification
by

Pacific Power & Light Co.

Kind of sample reported to us Coal
Sample taken at Jim Bridger
Sample taken by Pacific Power & Light Co.
Date Sampled 12-14-77
Date Received 12-21-77

Sample No. 12-14-77
Dcn Sakata
P.O. No. 4442-19

CABLE ADDRESS COMTECO

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 328 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 · AREA CODE 312 728-8434

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P.O. No. 4442-19

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<u>PROXIMATE ANALYSIS</u>			<u>ULTIMATE ANALYSIS</u>		
	<u>As received</u>	<u>Dry basis</u>		<u>As received</u>	<u>Dry basis</u>
% Moisture	18.89	xxxxx	% Moisture	18.89	xxxxx
% Ash	9.65	11.90	% Carbon	54.47	67.15
% Volatile	29.56	36.45	% Hydrogen	3.71	4.57
% Fixed Carbon	41.90	51.65	% Nitrogen	0.75	0.93
	100.00	100.00	% Chlorine	0.00	0.00
Btu	9418	11612	% Sulfur	0.45	0.55
% Sulfur	0.45	0.55	% Ash	9.65	11.90
			% Oxygen (diff)	12.08	14.90
				100.00	100.00

<u>SULFUR FORMS</u>			<u>FUSION TEMPERATURE OF ASH</u>		
	<u>As received</u>	<u>Dry basis</u>		<u>Reducing</u>	<u>Oxidizing</u>
% Pyritic Sulfur	0.19	0.24	Initial Deformation	2120°F	2200°F
% Sulfate Sulfur	0.01	0.01	Softening (H=W)	2240°F	2255°F
% Organic Sulfur (Diff)	0.25	0.30	Softening (H=1/2W)	2410°F	2440°F
% Total Sulfur	0.45	0.55	Fluid	2505°F	2650°F

HARDGROVE GRINDABILITY INDEX = xxxxx at xxxxx % Moisture

% EQUILIBRIUM MOISTURE = xxxxx

FREE SWELLING INDEX = xxxxx

LWT/pd/bn

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.
L. W. Taylor
L.W. TAYLOR, Western Division Manager



LWT/bn

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<u>MINERAL ANALYSIS OF ASH</u>	<u>Percent Weight Ignited Basis</u>
Silica, SiO ₂	63.10
Alumina, Al ₂ O ₃	14.36
Titania, TiO ₂	0.77
Ferric oxide, Fe ₂ O ₃	4.00
Lime, CaO	5.72
Magnesia, MgO	2.10
Potassium oxide, K ₂ O	0.77
Sodium oxide, Na ₂ O	1.75
Sulfur trioxide, SO ₃	6.28
Phos. pentoxide, P ₂ O ₅	0.16
Undetermined	0.99
	100.00

Alkalies as Na₂O, Dry Coal Basis = 0.27
Silica Value = 84.22
Base: Acid Ratio = 0.18
ESTIMATED VISCOSITY at critical viscosity
Temperature of 2610 °F = >2000 Poises
T₂₅₀ Temperature = >3100

Respectfully submitted,
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L. W. Taylor
L.W. TAYLOR, Western Division Manager



A free pamphlet is available from the Bureau entitled, "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request to the Bureau of Reclamation, Engineering and Research Center, PO Box 25007, Denver, Federal Center, Bldg. 67, Denver, CO 80225, Attn D-922.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.