

NOTICE CONCERNING COPYRIGHT RESTRICTIONS

This document may contain copyrighted materials. These materials have been made available for use in research, teaching, and private study, but may not be used for any commercial purpose. Users may not otherwise copy, reproduce, retransmit, distribute, publish, commercially exploit or otherwise transfer any material.

The copyright law of the United States (Title 17, United States Code) governs the making of photocopies or other reproductions of copyrighted material.

Under certain conditions specified in the law, libraries and archives are authorized to furnish a photocopy or other reproduction. One of these specific conditions is that the photocopy or reproduction is not to be "used for any purpose other than private study, scholarship, or research." If a user makes a request for, or later uses, a photocopy or reproduction for purposes in excess of "fair use," that user may be liable for copyright infringement.

This institution reserves the right to refuse to accept a copying order if, in its judgment, fulfillment of the order would involve violation of copyright law.

SUCCESSFUL FLUID MANAGEMENT OF THE SALTON SEA RESERVOIR

Anthony J. Adduci
U. S. Department of Energy
San Francisco Operations Office

Introduction

This paper has been extracted from several reports including the final report on the Geothermal Loop Experimental Facility and discussions with several persons currently in the process of managing geothermal fluid production utilization and disposal at the Salton Sea Geothermal Reservoir.

Background

The Salton Sea Geothermal Reservoir has been known to exist for at least 15 years. It was first produced by Southern Pacific Land Co., Phillips Petroleum, Morton Salt and other firms for various reasons, one of which was the extraction of heat.

All of these original explorers found the production unprofitable due to well plugging, high total dissolved solids in the fluid and other reasons. The South Salton Sea area still has abandoned sites as evidence of these attempts.

In 1975-1976 San Diego Gas & Electric and the U.S. Department of Energy (at that time (ERDA) began a 50-50 shared cost venture on the geothermal loop experimental facility. The initial objective was to show a multi-stage (4-stage) flash binary system would extract the heat from the geothermal fluid, utilize it to make electricity and dispose of the waste water and solids.

The Magma Power Company, the geothermal resource owner, agreed to provide fluid to GLEF under a special contract with SDG&E. Magma also supplied labor, data and self funded experiments which contributed greatly to the success of the GLEF.

Initially the system would be operated to assure sufficient vapor quantities to support a 10 MW design capacity turbine generator and then the turbine-generator would be added to produce power.

In the ensuing months it was obvious that "fluid management" would become the overall objective of the GLEF.

The Salton Sea geothermal reservoir (referred to as the reservoir) yields a fluid of 375°F (190°C) at a pressure of 150 psig (11.2 atm) and a flow of 324,000 lbs/hr (146,934 Kg/hr) liquid, 64,000 lbs/hr (29,024 Kg/hr) vapor, 12,000 lbs/hr (5,442 Kg/hr) gases and 200,000 parts per million of dissolved solids (see Figure No. 1 for solids and gas details).

The facility was initially to use flow from two wells (800,000 lbs/hr or 362,800 Kg/hr) for fluid production and one well for fluid injection.

ELEMENTAL RANGE FOR WELLHEAD BRINE

MAC-MAX NO. 1 WELL

WOOLSEY NO. 1 WELL

<u>ELEMENT</u>	<u>HIGH</u>	<u>LOW</u>	<u>AVERAGE</u>	<u>HIGH</u>	<u>LOW</u>	<u>AVERAGE</u>
Cl	126,000	107,000	112,800	146,000	94,000	121,000
Na	46,500	39,000	41,700	54,600	29,600	42,700
Ca	21,400	16,300	19,400	28,300	16,700	22,900
K	8,130	6,500	7,350	14,100	5,830	10,200
Mn	563	462	520	903	498	718
Sr	430	370	393	472	292	382
Zn	229	184	203	313	172	256
Si	243	159	213	236	152	204
Ba	154	111	130	195	79	142
Li	175	146	156	197	122	162
Fe	145	117	126	320	152	236
Mg	106	88.2	96.7	116	67	87
Pb	38.7	8.0	21.0	68	24	49

Note: All measurements are ppm

(NON CONDENSIBLE GASES AT WELLHEAD
DATA GENERALLY SAME FOR BOTH WELLS)

	DECEMBER 1976 % OF TOTAL GAS	AUGUST 1979 % OF TOTAL GAS
CO ₂	98.14	98.92
CH ₄	0.68	0.51
N ₂	0.02	0.57
O ₂	*ND	*ND
H ₂	*ND	*ND

*ND implies none detected

Fig. 1.

The surface plant was a 4 stage flash/binary system See Fig. 2 where fluid would be flash 4 times: at 370°F (187.6°C), 165 psia (11.2 atm); 308°F (153°C), 60 psia (4.08 atm); 262°F (127.6°C), 28.3 psia (1.92 atm); and finally 221°F (104.9°C), 13.3 psia (0.90 atm). After each flash the steam was scrubbed with vertical plate steam scrubbers and then the steam (vapor) was passed through normal shell and tube heat exchangers.

The "working fluid" (fluid to be vaporized and to drive the turbine; flowed from exchanger No. 4 to exchanger No. 1 to establish the counter flow process.

The non-vaporized geothermal fluid (the liquid) was injected back into the ground and the condensate was used for cooling water make up.

During initial operation of the 4 stage flash/binary system distilled water would be the "working fluid."

The vaporized distilled water would then be replaced with a hydrocarbon prior to turbine-generator installation.

All of this planning and design was based upon preliminary testing and analysis which took place from 1973 through 1974.

Initial system start-up on 3 May 1976 encountered problems with well flow and from that point on the 4 stage flash/binary system achieved a less than 40% plant availability time.

Problems: The basic problem was poor chemical data on which the design was based; because of this a series of problems occurred, all of which are chemical in cause.

- a. Scaling up of pipes, tanks, thermal wells, fluid extraction ports, valves and injection the wells
- b. Materials failures and degradation in the "working fluid" heat exchangers, injection pump bearings, and in the fluid system in general

These problems were so bad that the actual heat and mass balance for the plant could not be calculated because accurate data collection was impossible due to instrument failure.

The injection of fluid though initially easy became very difficult. In order to maintain liquid disposal injection pressures were raised and formation fractures were opened. The injection pressure was then dropped until these fractures were plugged, and then the process was repeated. This practice is not acceptable since fracturing of unknown direction has many potential catastrophes associated with it.

Pipe plugging and valve inoperation was the cause of great concern at times, plus it resulted in unstable system operation at certain times.

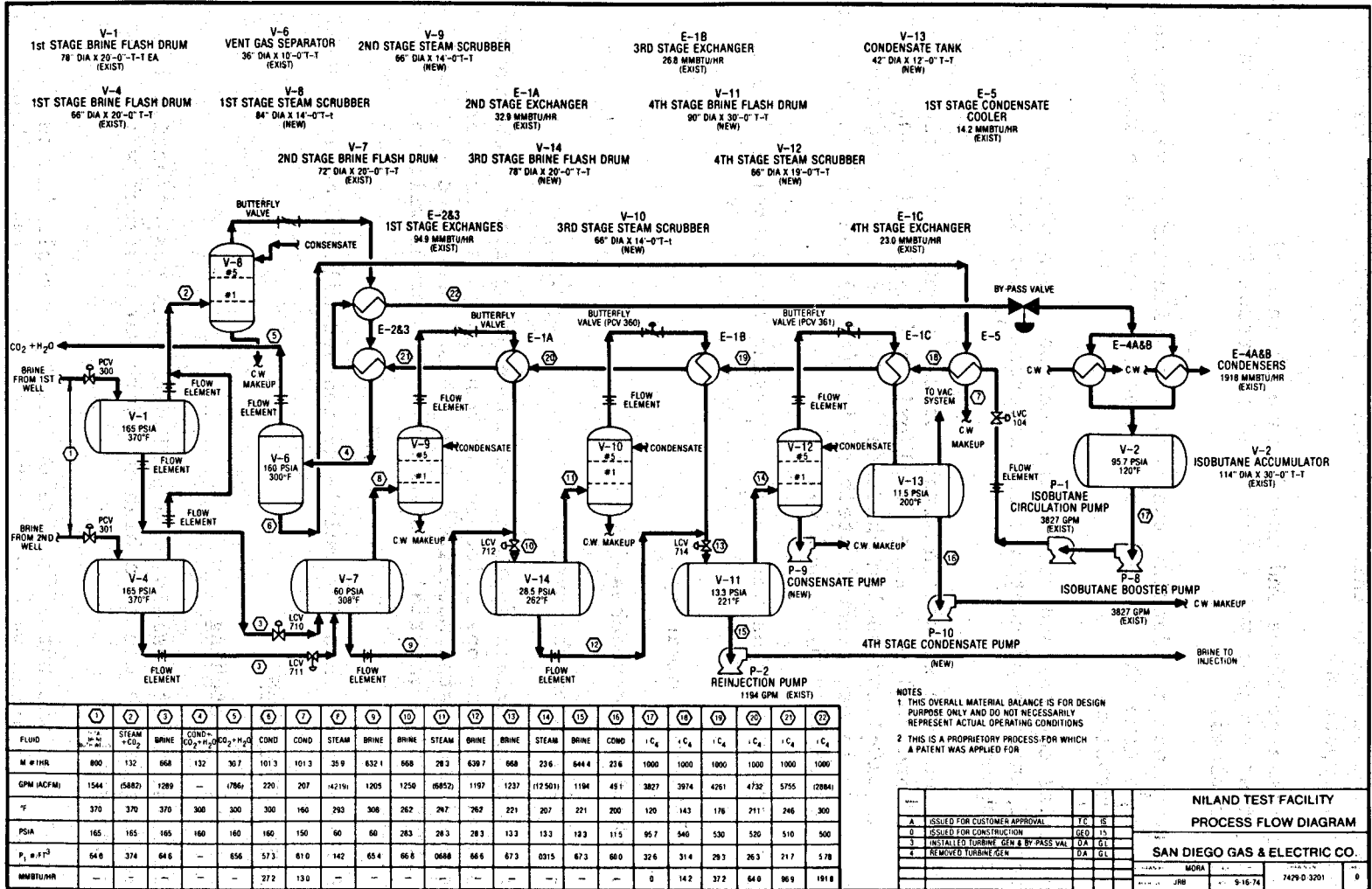


Fig. 2. GLEF process schematic four stage flash/Binary cycle.

Along with the fluid problems there were chemistry problems with the cooling water which caused corrosion of the shell and tube condensers. This problem however was not unique to this sea reservoir and therefore was considered as of secondary importance.

Because of these problems and the failure of initial solution to solve these problems a test program was established to attack the scaling and the materials problems.

The first item was to identify the scale constituents at various points in the plant to define the methods to be used in a systematic approach to solving the problem.

Also, material coupons and small pipe sections were placed in the system to determine if the use of coatings or different materials would reduce scaling and/or corrosion.

The scaling analysis showed the front of the plant to contain a heavy metal sulfide (FeS and PbS) plus some metal oxides (Fe₂O₃ and Fe₃O₄) plus silica (SiO₂) and sodium chloride (NaCl). As the fluid ended its journey the scale was predominately silica (SiO₂) and sodium chloride (NaCl). (See Figures 3, 4, 5 & 6.)

Three separate approaches were used in trying to control/manage the scaling problem.

- a. Mechanical cleaning
- b. Chemical approaches
- c. Re-design of the system

(The alternate materials approach was an on-going test which was not to be incorporated into the operation due to many factors. However, the data on the worth of the tested materials under these conditions is valuable to future plant design materials selection. This paper will not cover materials test results.)

Each of these approaches was multi-faceted and will be handled separately.

Mechanical Approaches

Hydroblasting & etching

The hydroblasting of vessels on a periodic basis was effective but costly. Hydroblasting is the use of a high pressure water stream which physically removes the scale.

The initial test was not effective on the tough scale in the 1st and 2nd stage steam separation vessels. After acid and/or base etching of the scale the hydroblasting was effective. The expense of hydroblasting was high, and therefore the frequent use of this procedure was not recommended.

Date	5/23/77	5/23/77	5/23/77
Location	Below Fluid Level	Floor Debris	Venturi On Outlet
Thickness	0.3-0.5 cm	0.1-2 cm	0.2-0.5 cm
General Appearance Color	redish-brown black porous	black formed by particle conglomeration	black very hard
	Wt%	Wt%	Wt%
Fe	25.25	24.20	22.55
Cu	0.18	0.30	0.21
Zn	0.07	0.15	0.09
Mn	1.53	1.07	1.78
Pb	0.91	8.25	5.60
Ca	1.50	0.85	1.10
Al	0.89	1.64	1.15
Si	16.65	16.65	16.10
Ba	0.13	0.08	1.60
Mg	0.11	0.12	0.08
Na	2.50	0.46	0.78
Co ₃	*ND	*ND	*ND
S as S ⁻	0.25	1.55	0.97

*ND implies none detected

Fig. 3. First stage separator scale.

Date	5/23/77	5/23/77	5/23/77
Location	Well below Fluid Level	Floor Debris	Venturi On Outlet
Thickness	0.18-1.8 cm	to 2.5 cm	0.7 mm
General Appearance Color	black multi-layered	porous grains built on central portion black	hard black
	Wt%	Wt%	Wt%
Fe	25.55	23.85	21.25
Cu	0.13	0.10	0.50
Zn	0.14	0.22	0.10
Mn	1.10	1.23	2.37
Pb	0.08	.52	0.05
Ca	2.10	1.15	1.15
Al	0.85	0.75	1.15
Si	17.85	19.20	19.65
Ba	1.04	0.81	0.42
Mg	0.05	0.65	0.43
Na	3.25	1.40	2.05
Co ₃	*ND	*ND	*ND
S	0.45	0.51	0.23

*ND implies none detected

Fig. 4. Second stage separator scale.

Date	5/23/77	5/23/77	5/23/77
Location	Well below Fluid Level	Floor Debris	Venturi On Outlet
Thickness	0.5-1 cm	to 2 cm	1.5 cm
General Appearance Color	porous yet hard	porous black	hard multi-layered black, green
	Wt%	Wt%	Wt%
Fe	16.65	21.60	3.10
Cu	0.16	0.74	0.41
Zn	0.26	0.16	0.06
Mn	1.07	1.45	0.36
Pb	0.51	0.93	0.26
Ca	1.45	0.95	1.55
Al	0.61	0.87	0.24
Si	18.30	18.70	34.15
Ba	1.20	1.10	0.18
Mg	0.31	0.37	0.12
Na	2.95	1.00	2.60
Co ₃	*ND	*ND	*ND
S	1.26	1.55	0.18

*ND implies none detected

Fig. 5. Third stage separator scale.

Date	5/27/77	5/27/77	5/27/77
Location	Flash Vessel Wall	P-2 Suction Inlet to First Impeller	P-2 Casing
Thickness	0.5 cm	0.6-1 cm	
General Appearance Color	light olive soft	hard black ochre film	soft porous gray
	Wt%	Wt%	Wt%
Fe	2.95	1.70	2.10
Cu	0.21	19.80	0.24
Zn	0.09	0.09	0.10
Mn	0.24	0.25	0.30
Pb	0.22	0.63	0.18
Ca	0.85	0.55	0.40
Al	0.13	0.28	0.41
Si	31.80	28.70	38.75
Ba	4.10	0.60	1.25
Mg	0.26	0.27	0.47
Na	0.55	0.26	0.20
Co ₃	*ND	*ND	*ND
S	1.20	0.40	0.77

*ND implies none detected

Fig. 6. Fourth stage separator and injection pump scale.

(After the plant re-design, however, the scale was not as well attached to the metal surface and thus the need for acid or base etching was eliminated.)

In conclusion, hydroblasting is the most effective method of scale removal during scheduled maintenance down times.

On Line Hydroblasting or Cavitation Cleaning

This is a system where high pressure water is forced through a nozzle. The water has air bubbles which expand past the nozzle; the bubbles burst at the surface of the scale setting up a shock wave and dislodge the scale from the surface on which it formed.

Cavitation cleaning was performed periodically while the plant was operating to remove scale buildup. The procedure was to connect a high pressure water line to the nozzle connection exterior to the geothermal fluid system and flow the high pressure water thru the nozzle to perform the cavitation cleaning.

Three types of removals were tried. The first was in a straight pipe, the second was on valve seats and the third was in a thermal well.

The first two tests were inconclusive as to results due to technical problems with the support equipment. Specifically, the water pressure required for adequate cleaning was not available due to lighter than required hoses and connectors; before this could be corrected the GLEF operation was terminated.

The thermal well test had excellent results. The thermal well was cleaned at 7 day intervals. The temperature instrument reading was higher after each cleaning. Upon plant shutdown, the examination of the thermal well showed definite effects of cavitation cleaning. The scale was gone at the cleaning points and approximately 1 cm. thick in other areas of the well.

In conclusion, even though on-line cavitation cleaning had marginal results it does have potential for being an effective scale removal process. (In my opinion, cavitation cleaning efficiency is a function of the distance of the nozzle from the surface to be cleaned and the water pressure applied. In the reported results, as the distance increases the pressure to the nozzle increases exponentially. This pressure increase causes high support equipment costs to clean components where the nozzles have long distances from the nozzle tip to the surface where the scale is formed.)

"Pigging" of lines for Off Line Plant Cleaning

The operation of "pigging" is the forcing of a projectile through a pipe in order to scrape the sides of the pipe and remove the scale.

The "pigging" process was successful when using a wire brush pig (See Fig. 7) against moist silica scale deposits. However, when the silica scale dries and hardens the pigging operation is not effective.

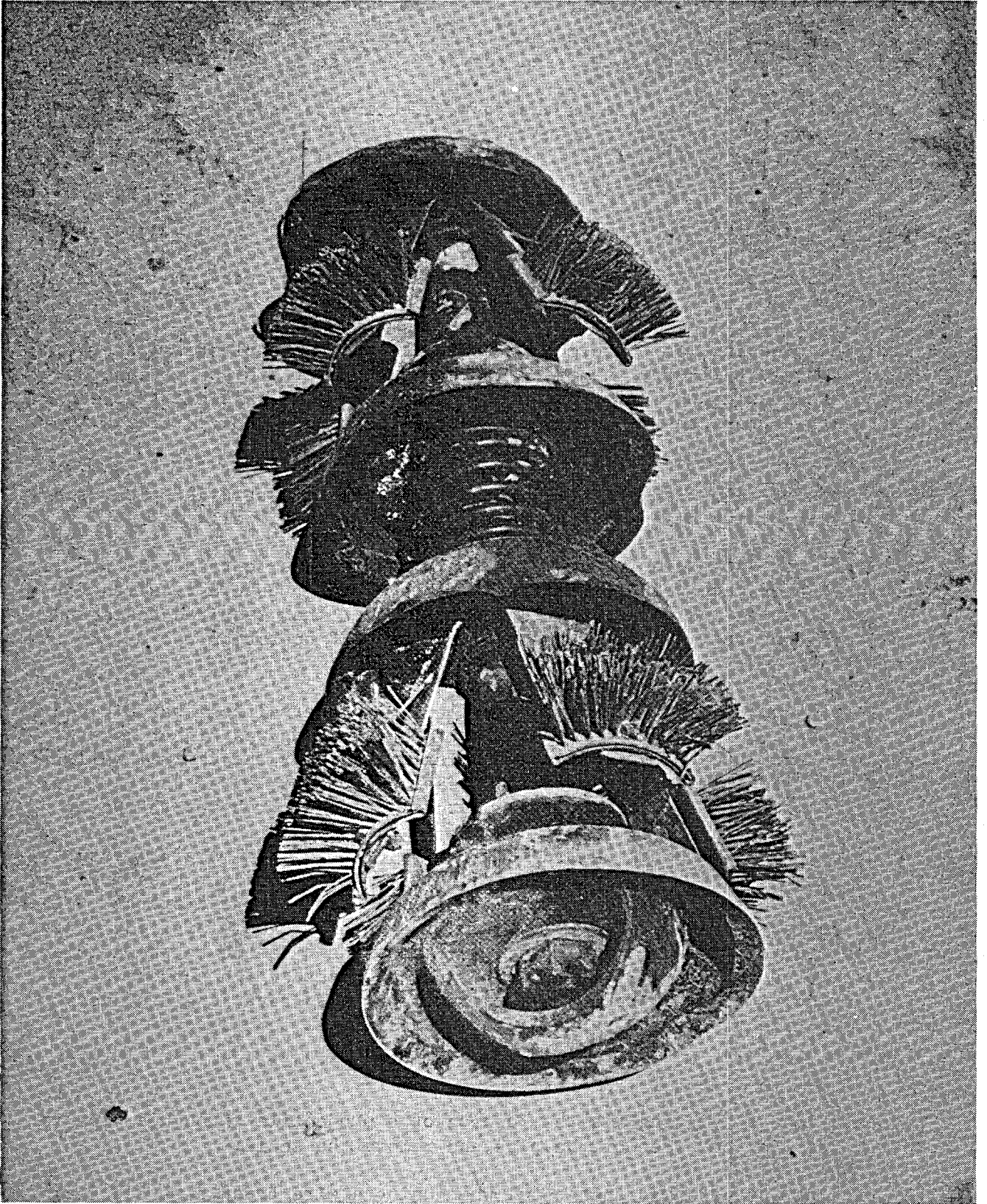


Fig. 7. T.D. Williamson wire brush pig (used).

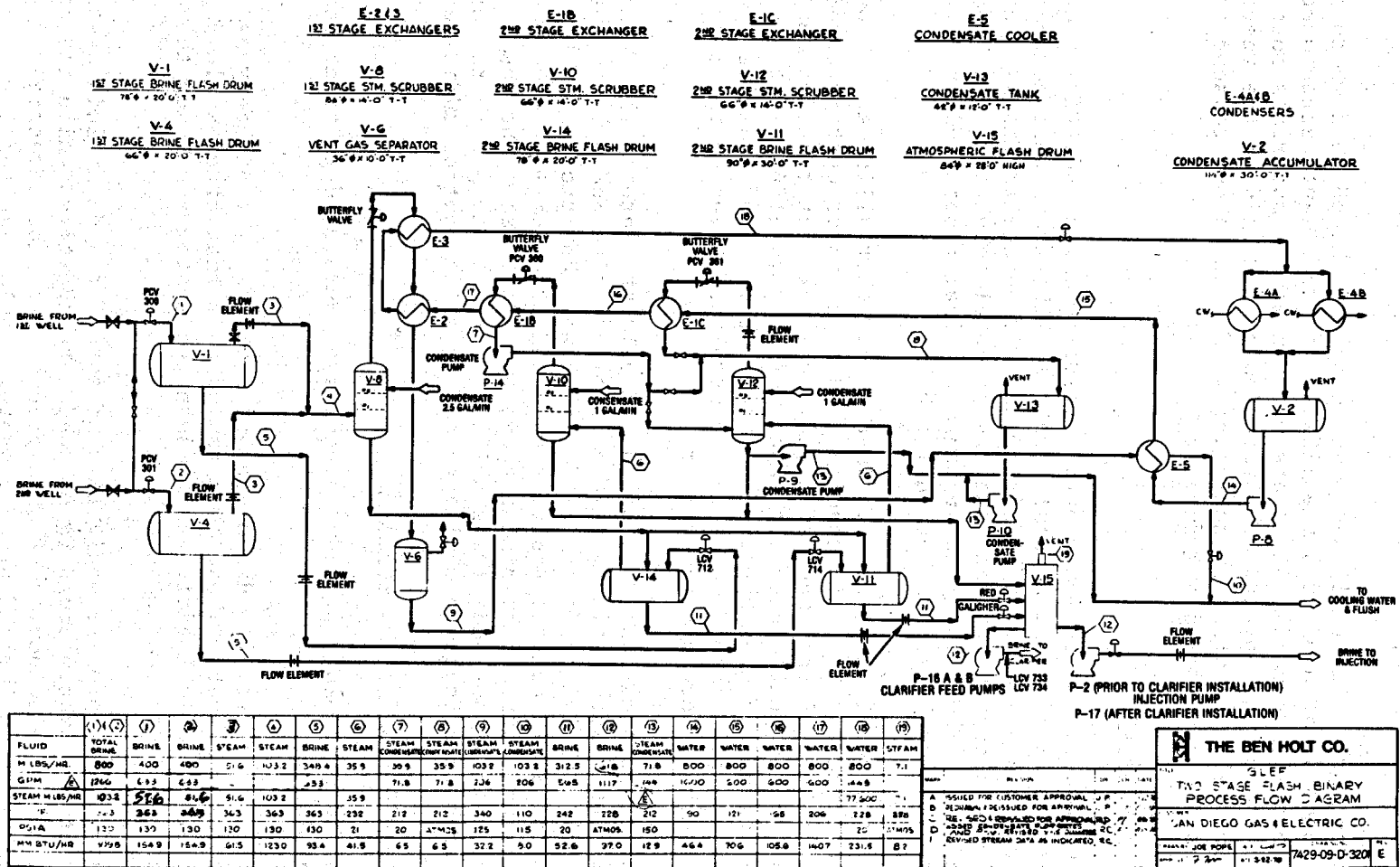


Fig. 8. GLEF two stage flash binary process flow diagram.

Chemical Scale Control

Acidification of the fluid: Fluid acidification was successful but had many disadvantages.

First, hydrochloric acid (HCl) was used to adjust the pH to 3 which is not economic. Second, at a pH of 3 the lifetime of the plant carbon steel piping is severely reduced. Alternate very expensive materials must be utilized in the surface plant. The reaction of the acid on the reservoir and injection well was also not acceptable. For the above reasons this solution was not considered any further.

Chemical Additives

Under a long and comprehensive program several chemical additives (over 65 in all) were tested for silica scale control. The tests were conducted at different temperatures and at differing additive concentrations. The details of these experiments and the experimental results are too numerous to mention here. They are given in the GLEF final report and in several reports by Lawrence Livermore National Lab.

Conclusions reached from these experiments were that silica scale control could be achieved with certain chemical additives under certain conditions. However, since all of the successful additives were not tested under all conditions (due to GLEF closure in Sept. 1979) it is difficult to totally assess the worthiness of a specific additive or group of additives. The question of the effects of these scale control additives on the injection well and reservoir were not investigated.

As a matter of information: one of the experiments late in the Program was to combine a successful silica scale control additive and a known carbonate scale control additive to determine if there were any problems with interference of one scale control additive with the other or if there were any other detrimental affects by mixing these two additives. The results showed no difference in either additive's ability to function, and there were no other detrimental effects in mixing these two scale control additives.

Chemical Leaching to Remove Scale

Using standard minerology procedures additives were used to treat scale already in place.

The results showed definite dissolving of scales almost directly as minerology texts direct. These results indicate that after scale deposition the use of minerological additives to wash the system and leach the metals will loosen and dissolve the scale.

Conclusion: Such a process would be successful if a dual fluid system was built so that one system could be flushed with additives while the other loop operated. The economics of this process were not investigated but it would appear that dual fluid process systems would make the idea uneconomic. However, if the metal recovery were to be profitable an entirely new economic picture would need study.

Mechanical Re-Design

This was accomplished to decrease scale especially in the lower temperature process areas and to decrease the complexity of a 4 stage flash/binary system.

Rather than treating this under the scaling treatment section it will be covered under the next sections.

2 Stage Flash/Binary System

In 1978 the plant was redesigned from the 4 stage flash/binary system to 2, 2 stage flash/binary systems (named train A and train B) both capable of 400,000 gal/min flow each. The steam separator, scrubber, heat exchanger scheme was kept intact. (See Fig. 8)

The first stage flash was at 363° F (183.7° C) and a pressure of 130 psia (8.84 atm), the second stage flash was at 242° F (116.5° C) at a pressure of 20 psia (1.37 atm). There were two additions to the system, the first was an atmospheric flash tank where the un-flash liquid constituent was brought to atmospheric pressure. The second addition was a clarifier/sand filter system for processing the unflushed liquid effluent prior to injection. (The clarifier system will be discussed under injection fluid treatment.)

The result of the re-design was a slight loss of heat extraction efficiency but a plant availability factor of over 60%. This was an increase of over 20% in plant availability over the 4 stage flash/binary system.

As stated before another reason why the 2 stage flash/binary system was installed was to reduce or aid in scale control. The new system did have that effect. First it reduced the tenacity of the scale in the first stage steam separator tanks by making it more brittle and susceptible to hydro-blasting without etching as mentioned earlier.

Second, it reduced the quantity of scale in the 2nd stage flash tank and transferred most of the (silica) scale to the atmospheric flash tank and downstream piping leading to the Clarifier system. This positioning of the scale made it much easier to manage than when it was spread through the last two stages of the 4 stage flash/binary system.

Conclusion: The 2 stage flash/binary system appears to be the most acceptable plant scheme for this type of high salinity - high dissolved solid type of reservoir.

INJECTION TREATMENT AND OPERATION

As stated earlier liquid injection was at best troublesome and erratic. In order to keep the plant in operation waste liquid on occasion had to be stored while an injection well was overhauled so that it would again accept fluid.

In investigating this problem it was found that silica was the cause of the problem.

Silica precipitation is a sluggish reaction. As the temperature declines for a silica laden solution the silica is slow to come to a saturation equilibrium and therefore appears as a super-saturated liquid for a period of time.

In the injection process a silica laden solution has been dropped in temperature relatively quickly going through the plant system. Silica has precipitated, but the injection liquid is still super-saturated with silica. When the super-saturated liquid is injected and meets the reservoir face in the injection well the silica precipitates to achieve a saturated solution state. The silica precipitate blocks the reservoir pores from accepting liquid and causes the rise in injection pressure.

The solution to the problem was obvious. Treat the injection liquid so that silica saturation and not super saturation is present prior to injection.

Detention and settling was the first idea tried but the resulting injection liquid was still super-saturated (although not to as great an extent) with silica and the settling tanks were difficult to keep clean on a continuous process basis.

Flocculation with chemical additives was tried but the experimental results showed that the best flocking agent was precipitated silica.

In early 1978, the Magma Power Co. and the Envirotech Corps. began pilot experiments using a sewage sludge type reactor/clarifier to remove silica. The results were very successful bringing the suspended solids from 180 p.p.m. (parts per million) to 100 p.p.m. The silica in solution was also dropped from 390 p.p.m. to 200 p.p.m. The clarifier effluent was then filtered through a dual media filter and an injection liquid of 4-10 p.p.m. and a suspended silica content of 192 p.p.m. was ready for injection.

Based upon these results a system was designed using a reactor clarifier, a dual media sand filter, a thickener, a filter press and a holding tank for filter back wash. The construction was begun in late 1978, but the system was not started up until May 1979 due to several construction delays. (Fig. 9)

The theory on why the clarifier system operates is as follows:

Silica is a slow precipitator as mentioned before.

Also, as found in the flocking tests, silica is its own best flocking agent because the precipitated silica provides nucleation sites for further silica precipitation.

The reactor clarifier takes in account both of these phenomena by the use of 3 concentric tubes within the clarifier/reactor tank (Fig. 10). The center tube is the reactor where the precipitated silica is pulled up from the tank

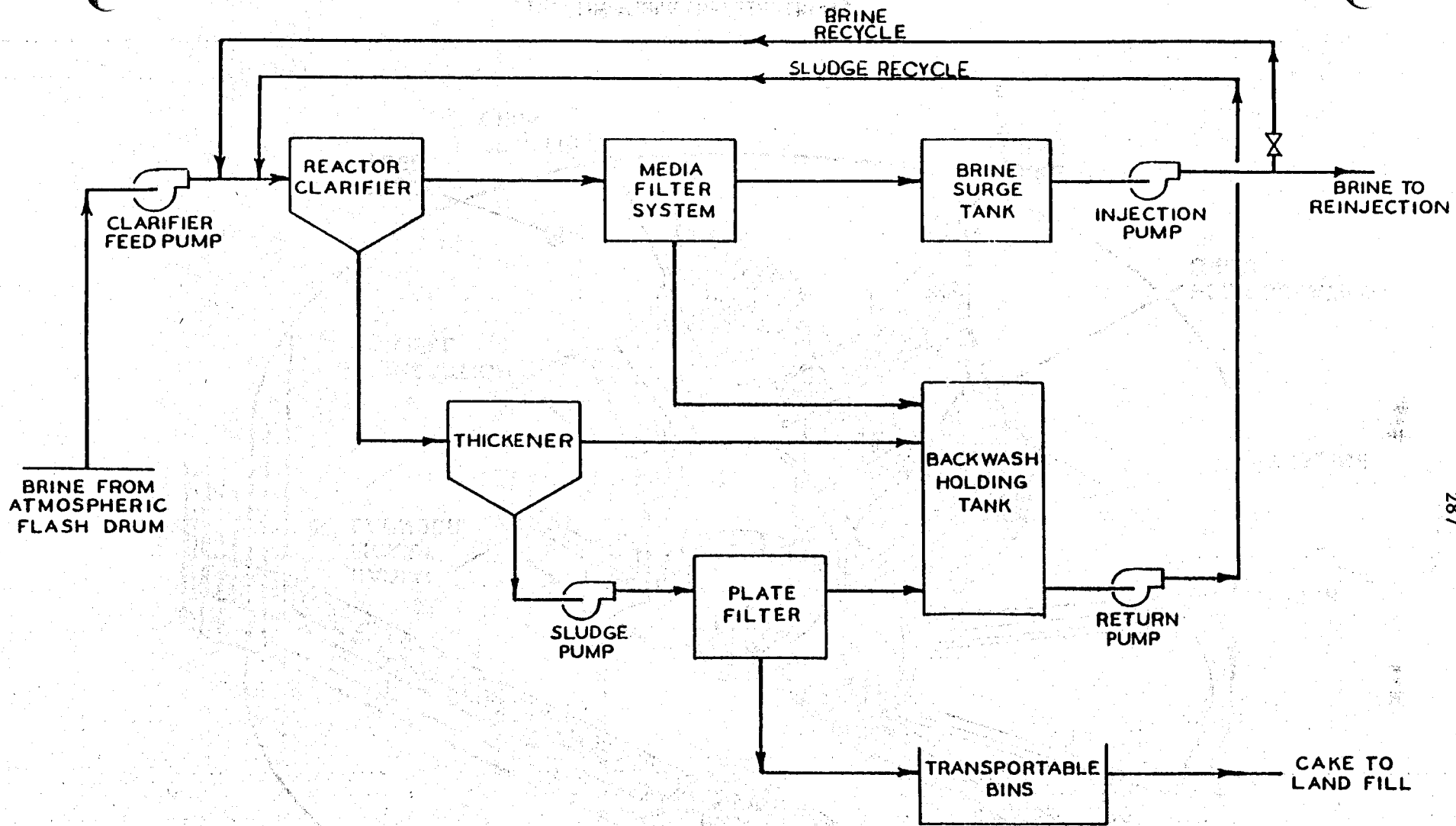


Fig. 9. Clarifier/filter installation process flow diagram.

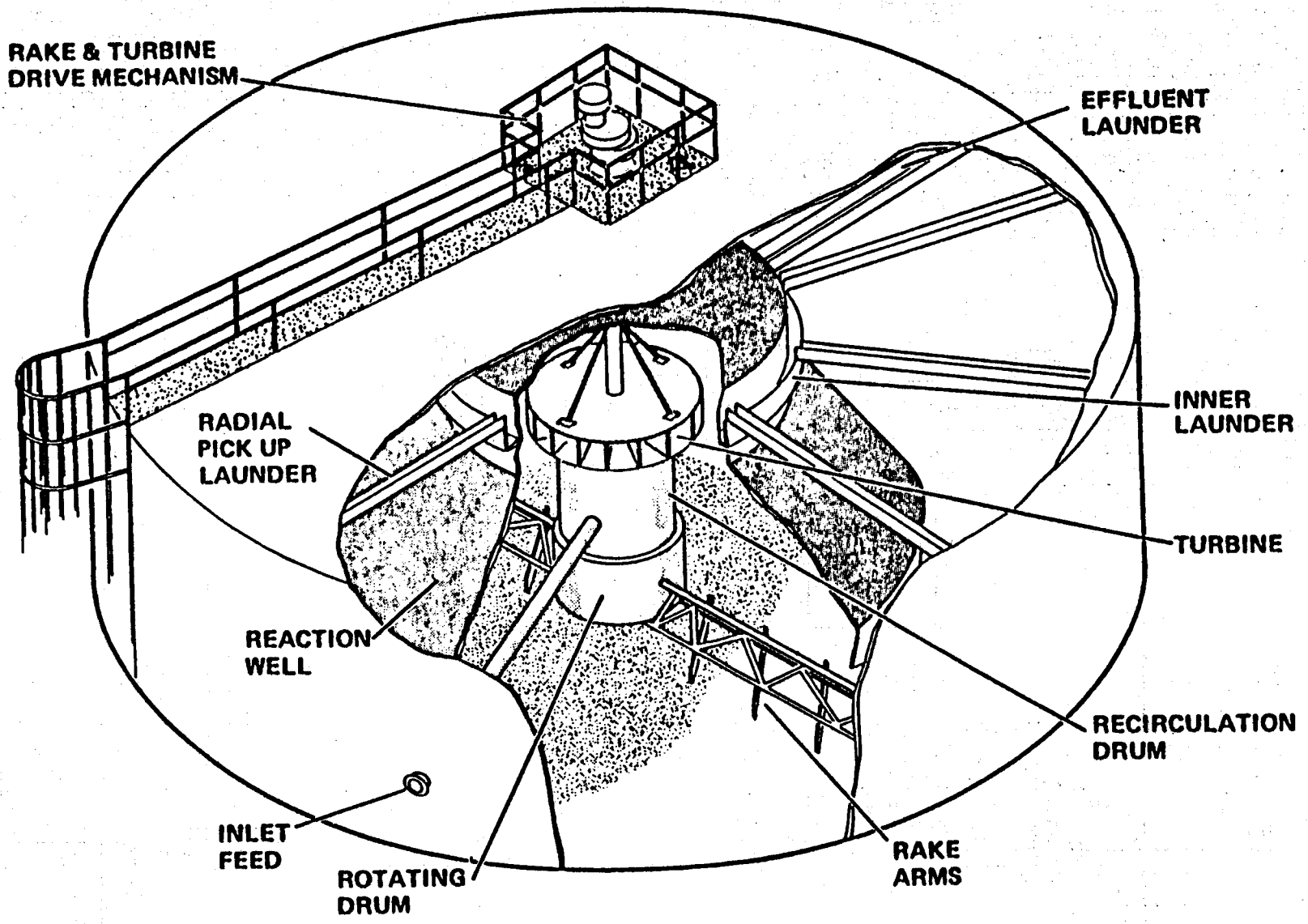


Fig. 10. Reactor/clarifier.

bottom and mixed with the new discharge liquid. The mixture then flows over the top of the first tube into the second tube where now the reaction of the silica in solution and the solid takes place. The precipitated silica slowly settles to the bottom. In the third tube the liquid rises leaving the solid silica on the bottom of the tank to be used for further precipitation. The excess solid silica is extracted for de-watering by a thickener and prepared for disposal by a filter press.

The other system components such as the sand filter and filter back wash holding tank are self explanatory. Also the liquid from the thickener & filter press are placed in the back wash holding tank.

The liquid in the back wash holding tank is returned to the clarifier/reactor for processing.

As usual, there were problems in system start up. The first was poor instrumentation and control, the next was optimizing the time the liquid spent in the reaction and clarification zones to assure complete reaction and adequate settling. Upon resolution of these problems the clarifier worked as designed.

The next problem to arise was the identification of heavy metal oxides in the injection liquid. The cause was air leakage into the clarifier thus allowing reaction with the metal ions not precipitated before in the system. The sealing of air intrusion to the feed back loop and clarifier remedied this problem.

The entire clarifier system operated from June '79 to Mid Sept. '79 and totaled less than 1000 hrs. of operation. This system proved its ability to clean the injection liquid as preliminary experiments had indicated. However, due to this short operating time of the system the long term capability of the system is still questionable. If the experiment had operated for 6 to 9 months without problems then the clarifier system would be a proven entity, but because of this short operation there is nothing which can be said about the system life with any confidence.

After the Sept. '79 shutdown the clarifier/reactor system was examined. There was no scale of any type on any of the system parts. The only apparent wear was some corrosion on the interior walls of the clarifier tank. This is easily remedied by coating the vessel inside.

As a matter of information, a silica scale control additive was tested in the operating clarifier system. The results showed the additives worked upstream of the clarifier and yet had no effect on the function of the clarifier/reactor system.

There are other injection liquid clean up schemes or methods to circumvent the silica precipitation problem which were not tried at the GLEF.

One of these methods which was not tried was "hot injection".

Hot injection involves taking only a portion of the available heat out of the produced fluid and then injecting it in order to keep silica in solution.

GLEF did not try this scheme for two reasons. First, it did not appear reasonable to give away this heat which was difficult to get; and second, it appeared that the precipitates which appear at higher temperatures (heavy metal sulfides) would cause injection plugging if the silica did not.

Other firms working with this reservoir have tried "hot injection" and have had injection well plugging problems for the reason mentioned above.

The conclusion reached therefore at the GLEF and by other firms trying to produce the Salton Sea reservoir is that the only method of cleaning liquid for injection into this reservoir is a reactor clarifier sand filter type system.

There are ,at the present time, firms in the process of expanding the use of the reactor clarifier principles to apply it to flash vessels. Also other firms are investigating methods of accelerating clarification by using new flocculating chemicals. If this is achieved the capital cost of the clarifier system can be reduced. Both of these experiments are on going and privately funded.

At this point I would like to conclude this paper since all of the major items leading to the success of the GLEF have been discussed.

CONCLUSION

In summary, the following items have been accomplished by GLEF:

- a. The use of a 2 stage flash/binary system is best for this reservoir and others of similar chemistry. Although it is not as thermodynamically efficient, it is in operation 20% more of the time than the more thermally efficient 4 stage flash/binary system.
- b. Off line cleaning can be accomplished within economic bounds by using hydroblasting or chemical leaching with a dual fluid system.
- c. On line cleaning and scale control chemicals still require development before they are ready for operational use.
- d. Injection liquid processing of a silica dominated reservoir is practically and economically accomplished by using a clarifier/sand filter system.

Based upon the GLEF work the Salton Sea reservoir will give rise to at least 170 MW of power in the next seven years.

This means that high salinity, high total dissolved solids silica dominated reservoirs can operate economically.