Functional Conceptual Design Criteria - 5MW_e Salt-Gradient Solar Pond Power Plant at Great Salt Lake

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August 1983

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FUNCTIONAL CONCEPTUAL DESIGN CRITERIA
- 5MW_e SALT-GRADIENT SOLAR POND
POWER PLANT AT GREAT SALT LAKE

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FOREWARD

This report documents functional criteria for the conceptual design of a solar salt pond power plant located at the Great Salt Lake in the State of Utah. The study was performed by the Pacific Northwest Laboratory (PNL) for the U. S. Department of Energy and was part of a series of solar pond engineering studies conducted at PNL. The entire Solar Pond Engineering Program consisted of four tasks.

Truscott Brine Lake Feasibility Study - Working with the U.S. Army Corp of Engineers, PNL evaluated the technical and economic feasibility of building a solar pond power plant at Truscott Brine Lake. Truscott Brine Lake is part of Area VIII of the Arkansas-Red River Chloride Brine Control Project.

Great Salt Lake Feasibility Study - This task consisted of investigating the economic feasibility of constructing a power generating facility using a solar salt pond in the Great Salt Lake region.

Site Comparison - The major sites proposed for the location of a large solar salt pond test facility were to be compared based on economics, performance and site characteristics.

Design Handbook - PNL was to assemble a design handbook for solar salt ponds which reflects the site-specific aspects of design and cost.

Task 1 is reported elsewhere (Tulsa District, U.S. Army Corp of Engineers, 1982) while Tasks 3 and 4 were to have been completed in FY 1983, but were closed out due to a change in the total project direction. This document presents the functional criteria for a conceptual design that resulted from the preconceptual design conducted as part of the Great Salt Lake Feasibility Study.

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FUNCTIONAL CONCEPTUAL DESIGN CRITERIA - 5MW_e SALT-GRADIENT
SOLAR POND POWER PLANT AT GREAT SALT LAKE

1.0 INTRODUCTION

Salt-gradient solar ponds have been shown to be potentially inexpensive low temperature heat sources. Previous feasibility studies have been conducted for the Salton Sea in California (by the Jet Propulsion Laboratory) and for Truscott Brine Lake in Texas (by the U. S. Army Corps of Engineers). Both of these sites are attractive for salt-gradient solar ponds because they have high insolation rates, warm weather, and available dilute brine, among other things. Although solar ponds are capable of supplying heat in a wide variety of circumstances, their inherent long-term heat storage capability makes them especially attractive at high latitudes where available insolation is often mismatched with the peak energy demand. This, in conjunction with the large supply of concentrated brine, makes the Great Salt Lake a third attractive site for a salt-gradient solar pond.

In order to determine the best location for a large engineering test facility, the U. S. Department of Energy has funded a comparison of the three sites to be conducted by the Pacific Northwest Laboratory (PNL). As part of this study, PNL was asked to develop a preconceptual design of a solar pond power plant located at the Great Salt Lake. We accomplished this by doing feasibility and optimization studies at PNL and then used the results to define the functional criteria for a preconceptual design and cost estimate, which would be done by an architect-engineering firm. This report documents the functional criteria for the Great Salt Lake design.

1.1 SALT-GRADIENT SOLAR POND

To understand the performance of a salt-gradient solar pond, it is first important to understand why an ordinary pond (i.e., a fresh water pond or a saline pond with uniform density) cannot collect large amounts of solar energy. In an ordinary pond, when the water absorbs solar energy, its temperature

increases and its density decreases. The water near the surface is cooled as heat is dissipated to the atmosphere, increasing its density. The warmer, less dense water from the bottom of the pond rises to the surface, causing a fluid circulation known as natural convection. At the surface, heat contained in the warmer water is again dissipated to the atmosphere. Thus, an ordinary pond is constantly turning over, losing most of the solar energy that it absorbs.

In a salt-gradient solar pond the process of natural convection is suppressed by the construction of a salt-gradient in the pond. Concentrated salt water at the bottom of the pond heats up due to the absorbed solar energy but still remains heavier than the fresher water above it, preventing natural convection. In practice, a salt-gradient pond would consist of three layers: a storage zone of highly concentrated brine, a gradient zone with salt concentration gradually decreasing from bottom to top, and an upper convective zone of light brine or fresh water (Figure 1). The purpose of the storage zone is to absorb and store solar energy. The purpose of the gradient zone is to insulate the storage zone and to prevent natural convection. The upper convective zone forms naturally by wind, evaporation, precipitation, and diurnal heating and cooling. Since it has no positive benefit for the pond, the depth of this layer should be kept at a minimum.

Heat trapped in the storage zone can be extracted by in-pond or out-of-pond heat exchangers. Because of corrosion and maintenance problems and because of the large pond size, out-of-pond heat exchangers are typically recommended. The hot brine is extracted from near the top of the storage zone and used to vaporize a working fluid. The cold brine is returned to the bottom of the storage zone, usually on the opposite end of the pond from the extraction. The heated working fluid can be used either to generate electricity using a Rankine cycle heat engine, or for process heat applications.

1.2 PURPOSE OF FACILITY

The purpose of this solar pond plant facility would be to provide valid data on the cost, operation, and reliability of salt-gradient solar ponds as a means of producing power. This 5 MW_e facility would be large enough to

FIGURE 1. Salt-Gradient Solar Pond

adequately demonstrate the solar salt pond (SSP) technology to industry. In addition, experiments would be done to characterize problems associated with scaling the pond size from small test ponds to commercial size. Long-term operation and maintenance requirements would also be determined.

2.0 GENERAL FACILITY DESCRIPTION

The SSP power plant facility would be located near the southwest shore of the Great Salt Lake in the state of Utah.

The facility would include the salt-gradient solar pond, the evaporation pond to provide initial brine fill and makeup brine, the Rankine cycle heat engine, using ammonia as the working fluid, and all associated piping for brine, ammonia, cooling water, flushing water, and makeup brine transport.

In this design, the facility shall be instrumented sufficiently for normal power plant operation. Pond experimental instrumentation will not be estimated in this package.

Buildings will be provided to house a control room, offices, chemical laboratory, maintenance shops, main switchgear, and sanitary facilities.

2.1 DESIGN CODE REQUIREMENTS

2.1.1 Codes and Standards

The latest edition of the following codes and standards apply to the design and construction of this facility.

- Uniform Building Codes
- National Fire Protection Association
- National Electrical Code
- Uniform Plumbing Code
- Occupational Safety and Health (OSHA) Standards
- National Electrical Manufacturers Association (NEMA) Standards
- ANSI B31.1 Power Piping Code

2.1.2 Specifications

Specifications of the following groups apply to this project:

- American Institute of Steel Construction
- American Concrete Institute (ACI-318)
- American Society for Testing Materials (ASTM)
- American Welding Society

2.1.3 DOE Orders

The following orders shall be applied during design and construction of the project:

- DOE-4320.1 Site Development and Facility Utilization Planning
- DOE-5440.1A Implementation of the National Environmental Policy Act
- DOE-5480.1 Environmental Protection, Safety, and Health Protection Program for DOE Operations
- DOE-5481.1 Safety Analysis and Review System
- DOE-5700.6A Quality Assurance
- DOE-6430 General Design Criteria for Department of Energy Facilities

2.1.4 Federal Specifications

As applicable.

2.2 SITE SELECTION

The selection of the specific site at the great Salt Lake for the location of the SSP power plant was to be funded by Utah Power & Light and conducted by Utah State University, the University of Utah, and Weber State University. The site selection process was to consist of three phases.

Phase 1--Examination of general areas for overall suitability and selection of most promising general area

Phase 2--Selection of specific site within the most promising general area

Phase 3--Collection of detailed data on the selected site for use in detailed pond design.

The first phase of the study was conducted by Weber State University and Utah State University (Riley & Batty, 1981). The second phase of the study was to be conducted concurrently with the pond design tasks with the results being available early in the design process. Due to funding constraints, funds were not available for Phases 2 or 3. This forced PNL to select a surrogate site based on the results of the Phase 1 study.

The two investigation teams from Weber State and Utah State identified potential sites around the lake and compared them according to selection criteria. The sites studied in the Phase 1 effort are shown in Figure 2. The general areas explored by Utah State are identified by the letters A through H and the general areas explored by Weber State are identified by the numbers 1 through 7.

The two site evaluations reached essentially the same conclusion, which indicated that the two best general areas are those identified in Figure 2 by 5 and G on the southwest shore and by 1 and H near Willard Bay midway up the eastern side of the lake.

The site selected as the surrogate site for the Engineering Test Facility was on the southwest shore of the lake at site 5 on Figure 2. A more detailed evaluation will be required before a final site selection can be completed.

Subsequent to the completion of the design criteria, an alternate site was proposed by representatives of the AMAX Corporation, a very large mineral extraction company in the vicinity of the SSP location. This site is located just west of a large AMAX impoundment basin (see Figure 3). This basin would be a convenient source of flushing and cooling water. In addition, concentrated brine from the AMAX ponds may be available for makeup. This alternate site has the advantage of being further from the Great Salt Lake and, therefore, less susceptible to changing water levels in the lake.

2.3 SITE CHARACTERISTICS

2.3.1 Insolation

Solar insolation is a fundamental data requirement. Monthly average insolation data, required for the design optimization, were developed from meteorological data collected at the Salt Lake City Airport and are presented in Table 1 (Cinguemoni et al., 1978).

2.3.2 Ambient Temperature

The ambient air temperature affects the thermal losses from the pond. Monthly average dry bulb and wet bulb temperatures from the Salt Lake City Airport were used in this study and are presented in Table 1 (Cinguemoni et al., 1978).

FIGURE 2. Possible Locations for a Solar Salt Pond Power Plant Around Great Salt Lake

FIGURE 3. Proposed AMAX Location for the SSP Facility

TABLE 1. Climatic Conditions Assumed for Great Salt Lake

Month	Dry-Bulb Temp. (°C) (°F)		Wet-Bulb Temp. (°C) (°F)		Insolation W/m ² (Btu/hr-ft ²)		Cooling Water Temp. (°C) (°F)	
January	-2.0	(28.4)	-3.9	(25.0)	72.7	(23.1)	4.0	(39.2)
February	0.8	(33.4)	-1.4	(29.5)	116.7	(37.0)	4.0	(39.2)
March	4.2	(39.6)	1.1	(34.0)	181.8	(57.6)	14.0	(57.2)
April	9.6	(49.3)	5.0	(41.0)	241.4	(76.5)	14.0	(57.2)
May	14.6	(58.3)	8.9	(48.0)	302.9	(96.0)	14.0	(57.2)
June	19.0	(66.2)	11.7	(53.1)	328.3	(104.1)	19.0	(66.2)
July	24.8	(76.6)	14.4	(57.9)	332.0	(105.3)	19.0	(66.2)
August	23.6	(74.5)	14.4	(57.9)	288.3	(91.4)	19.0	(66.2)
September	18.2	(64.8)	11.1	(52.0)	232.6	(73.7)	19.0	(66.2)
October	11.3	(52.3)	6.7	(44.1)	156.6	(49.6)	19.0	(66.2)
November	3.9	(39.0)	1.4	(34.5)	89.7	(28.4)	19.0	(66.2)
December	-0.9	(30.4)	-2.2	(28.0)	62.8	(19.9)	4.0	(39.2)

2.3.3 Cooling Water Temperature

The heat engine selected for this design uses once-through cooling from the Great Salt Lake. The efficiency of the heat engine is dependent on the cooling water temperature. Quarterly average temperatures for the Great Salt Lake are given in Table 1 (Sturm, 1980).

2.3.4 Evaporation

The net evaporation rate (evaporation minus rainfall) affects the evaporation pond, size required for initial brine production and for makeup brine concentration, as well as flushing water rates. Excellent evaporation data exist for the Great Salt Lake due to the large, commercial-scale evaporation being conducted in the area. For this study, a value of 1.14 m/yr (45 in/yr) was assumed (Arnow, 1980).

2.3.5 Available Brine Salt Concentration

The size of the evaporation ponds required for the initial fill of the solar pond and brine makeup production is also a function of the salt concentration of the available brine. The Great Salt Lake has quite a range of available brines from completely saturated in the north end to relatively fresh in the south end near the mouths of rivers. For this study, brine near the south end (near site) was assumed with a salt concentration of 134 kg salt/m³ brine (8.4 lb salt/ft³ brine).

2.3.6 Brine Composition

The composition of the dissolved solids in the Great Salt Lake is very similar to ocean water although considerably more concentrated. Typical brine composition for the Great Salt Lake is shown in Table 2.

2.4 SITE-SPECIFIC DESIGN REQUIREMENTS

2.4.1 Seepage

Seepage of brine from the solar pond is detrimental in several ways. First, it is a loss of salt from the storage zone that must be replaced to maintain the salinity gradient. Second, seepage causes a loss of heat from the storage zone, which decreases the efficiency of the pond. Third, seepage

of brine from the pond could pose an environmental hazard by contaminating surface or subsurface waters.

The Great Salt Lake area does not appear to pose any major seepage problems. The runoff from any leak would almost certainly end up in the lake, which is already very saline. Large ponding operations already exist around the lake for the extraction of minerals. A sewage lagoon recently completed in the area indicated that the permeability of the soil-in-place and the borrow material was very low (0.15 mm/day and 0.009 mm/day, respectively).

The maximum allowable seepage rate for the solar and evaporative ponds to be used in this design is 5.6 cm/yr (2.2 in/yr). This is representative of a pond lined with a bentonite liner.

TABLE 2. Typical Brine Compositions

Constituent	<u>Concentration in Brine, wt%</u>			<u>g/100 g Dissolved Solids</u>		
	GSL	Dead Sea	Ocean	GSL	Dead Sea	Ocean
chloride	14.10	17.5	1.94	55.20	65.1	55.4
sodium	7.60	3.3	1.08	29.80	12.3	30.8
sulfate	2.00	0.7	0.27	7.80	2.6	7.7
magnesium	1.10	3.4	0.13	4.30	12.6	3.7
calcium	<u>0.02</u>	<u>1.4</u>	<u>0.04</u>	0.06	5.2	1.1
Total wt%	24.82	26.3	3.46			

(From Flint, 1971)

2.4.2 Wind Loads

A wind rose for the area is presented in Figure 4 (Woodhall, 1980). The highest one-minute wind measured in the south arm of the Great Salt Lake (December 1977 through July 1978) was 51 mph. The recorded all-time high at Salt Lake City was 71 mph.

FIGURE 4. Wind Rose for the Southern Part of Great Salt Lake

2.4.3 Earthquake Loads

The facility must be designed in conformance with the Uniform Building Code, latest revision.

2.4.4 Flood Requirements

The Great Salt Lake water level varies from 1280 to 1284 m (4200 to 4212 ft). The probability of the lake level exceeding 1283 m (4210 ft.), however, is once every 200 years (Austin, 1980). Depending on the elevation of the selected site, consideration must be given to prevent encroachment of the lake into the solar pond during the 20-year life of the facility.

3.0 FUNCTIONAL REQUIREMENTS

3.1 CIVIL-STRUCTURAL

3.1.1 Solar Salt-Gradient Pond

The design of the solar salt-gradient pond has been the subject of many technical studies. Background information included here discusses the method by which a design was selected for the Great Salt Lake location.

An operating solar salt-gradient pond consists of 3 layers:

- The upper convective zone at low constant salinity and temperature
- The nonconvective zone in which both the salinity and temperature increase with depth, and
- The storage zone at high constant salinity and temperature.

The upper convective zone is caused by wind, evaporation, precipitation, and diurnal heating and cooling. It is inevitable in a solar pond, but since it provides no benefit to the pond, its depth should be minimized. Current research indicates that this layer can be maintained at a depth of .4 m, which was assumed for this study.

The main purpose of the nonconvective or gradient zone is to prevent natural convection from occurring. A thicker nonconvective zone provides more thermal insulation for the storage and prevents long-wave reradiation. On the negative side, a thicker nonconvective zone absorbs more of the available energy, requires a larger salt inventory, and causes a more expensive pond construction.

The depth of the storage zone determines the yearly variation in storage temperature. As the depth is increased, the variation is decreased. A deeper zone, however, takes longer to heat up and requires much more salt and more expensive pond construction.

The SOLPOND computer code, developed at the Solar Energy Research Institute (SERI), and the GCOST and ETRANS models, developed at PNL, were used to optimize the solar pond configuration (layer depths). The primary figure of merit selected for this optimization was the levelized energy cost.

This approach calculates the present value of all costs associated with the plant and converts this present value to an annualized cost which, over the lifetime of the plant, has exactly the same present value. Dividing this annualized cost by the annual energy output of the plant produces an energy cost which is constant, or levelized, over the plant's operating lifetime. One interpretation of the levelized energy cost (LEC) is that it is the price (at which the plant energy output could be sold) which, over the plant's lifetime, would exactly recover all costs associated with the plant. An alternative expression of the same concept is that the present value of all energy sold at the LEC would exactly equal the present value of all plant costs. The use of an LEC to compare alternatives is a powerful tool because it condenses the required revenue to recover all project costs into a single unit cost of energy. If all other factors of consideration (such as operating characteristics, capacity factor, risk, etc.) between two alternative plants are identical, the plant with the lowest LEC can clearly be judged to be the most economical alternative. Both the pond configuration and the total system were optimized based on economics.

The pond configuration selected to give the lowest levelized energy cost was:

- Upper convective zone depth = 0.4 m (1.3 ft), salt concentration = 0.5 kg salt/m³ brine (0.03 lb salt/ft³ brine). This is a fixed assumption.
- Nonconvective zone depth = 1.25 m (4 ft), salt concentration varies from 0.5 - 208 kg salt/m³ brine (0.03-13 lb salt/ft³ brine)
- Storage zone depth = 1.0 m (3.3 ft), salt concentration = 208 kg salt/m³ brine (13 lb salt/ft³ brine)

Before the solar pond can be sized for a particular application, however, the power plant must be designed and optimized because the overall cycle efficiency directly affects the required pond size. Again, GCOST and ETRANS were used to optimize the entire system (holding pond configuration constant). The system (heat engine, ponds, piping) that gave the lowest LEC was selected and is described in this report.

3.1.1.1 Solar Pond Description

The solar salt-gradient pond planned for the Great Salt Lake consists of one large pond with an area of 61.8 ha (152.7 acres). The pond will be essentially square to minimize dike lengths and the dimensions are 786 x 786 m (2580 x 2580 ft). The actual pond depth is 2.65 m (8.7 ft), but the dikes shall be 3.65 m (12 ft) high to allow a freeboard of 1 m (3.3 ft).

The pond bottom flatness is to be maintained within $\pm .15$ m (± 6 in), and it is to be sufficiently impermeable to conform to a maximum seepage rate of 5.6 cm/yr (2.2 in/yr).

3.1.1.2 Pond Operations

3.1.1.2.1 Salinity Maintenance

The salinity gradient constructed in the solar pond will degrade with time if it is not properly maintained. Salt from the near-saturated storage zone will diffuse upward to the low salinity, upper convective zone until eventually the pond will become a homogeneous mass. This migration of salt must be countered to maintain the salinity gradient in the pond. This is accomplished in two ways:

- 1) By adding high salinity brine to the storage zone, and
- 2) By flushing the surface with low salinity brine to remove the salt that has diffused upward.

Near-saturated brine must be added to the storage zone to replace the salt lost by diffusion upward and by seepage into the ground. Assuming a diffusion rate of 42 kg salt/m²/yr (8.6 lb salt/ft²/yr) and a seepage rate of 5.6 cm/yr (2.2 in/yr), the required makeup brine flow at 300 kg salt/m³ brine (18.7 lb salt/ft³ brine) is 212 liters/min (56 gpm).

The salt that diffuses upward out of the storage zone eventually ends up in the upper convective zone, where it must be removed. This is accomplished by constantly flushing the surface of the pond with low salinity water. As this water flows across the pond, it will pick up the diffusing salts so they can be removed. An accepted value for flushing water flow is .007 liters/min/m² (7.5 gpm/acre) of solar pond. For this case, then, with a solar pond

of 61.8 ha (152.7 acres), the required flushing water flow would be 4334 liters/min (1145 gpm).

3.1.1.2.2 Gradient Maintenance

If the solar pond gradient has been established properly and the salinity of the storage zone and the upper convective zone are maintained as discussed above, the gradient should require no maintenance. Occasionally, a portion of the gradient may contain insufficient salt to support the local temperature gradient, and local internal convective layers may form in the nonconvective zone. Correction of this situation can be done either by slowly injecting the proper density brine into the troubled area or by diffusing concentrated brine through the disturbed area at varying rates.

3.1.1.2.3 Upper Convective Zone Maintenance

Since the upper convective zone is caused primarily by wind effects on the pond, it is advantageous to use wave suppression devices. SERI suggests using floating PVC pipe lying perpendicular to the prevailing wind direction to cut down on the wave action. The pipe would have to be ultraviolet inhibited and would be arranged in rows about 10 m (33 ft) apart, or closer, if needed. It is expected that wave suppression devices will be required at the Great Salt Lake location.

3.1.2 Evaporation Pond

In order to provide concentrated brine both for the initial fill of the solar salt-gradient pond and for the makeup brine system, an evaporation pond is required. The size of the evaporation pond not only depends on the net evaporation rate and the salt concentration of the available brine discussed in Section 2.5, but also on the time allowed to produce the initial quota of brine. In this design, the evaporation pond was sized to deliver the full pond depth in two years. At the end of two years, the brine in the evaporation pond will be near saturation at 300 kg salt/m³ brine (18.7 lb salt/ft³ brine). This will be diluted with Great Salt Lake water at 134 kg salt/m³ brine (8.4 lb salt/ft³ brine) to form the desired layer concentrations.

3.1.2.1 Evaporation Pond Description

Using the above assumptions, the evaporation pond would be 1.75 m (5.75 ft) deep to avoid overconcentration and precipitation. Assuming that the near-saturated brine from the evaporation pond can be diluted with Great Salt Lake water, the evaporation pond area required to fill the solar pond in 2 years would be 18.2 ha (45 acres).

In addition to this initial requirement to fill the solar pond in 2 years, there is an ongoing requirement for near-saturated brine as makeup brine. After the initial fill, a portion of the evaporation pond must remain in use for the life of the plant. This will be referred to as the makeup pond (part of the evaporation pond) and the required area is 12.2 ha (30 acres).

3.1.2.2 Evaporation Pond Operation

During the period of evaporation for the initial fill of the solar pond (2 years), makeup water will be required from the Great Salt Lake to replenish the water evaporated from the evaporation pond. With a net evaporation rate of 1.14 m/yr (3.74 ft/yr) and an evaporation pond area of 18.2 ha (45 acres), the required flow is 395 liters/min (104 gpm).

During solar pond operation, a continuous supply of nearly saturated makeup brine is required to replace the salts lost from the storage layer by diffusion and seepage. For this design, the required makeup flow to the solar pond is 212 liters/min (56 gpm) at 300 kg salt/m³ brine (814 lb salt/ft³ brine). In order to supply this concentrated brine, a continuous flow of Great Salt Lake water at 134 kg salt/m³ brine (8.4 lb salt/ft³ brine) is required to the makeup pond. The required flow of Great Salt Lake water is 473 liters/min (125 gpm) for the life of the plant. A water and salt balance is shown in Figure 5.

3.1.3 Road and Walkways

A paved roadbed shall be provided as required from the nearest paved road to the construction site. A paved parking area capable of accommodating 5 automobiles shall be provided adjacent to the control/service building. An asphaltic concrete pad shall be provided immediately adjacent to the control room for parking the trailer-mounted DAS system.

FIGURE 5. SSP System Water and Salt Balance

All roads, walkways, and parking lots damaged by heavy machinery during the course of construction or by excavation shall be restored to their original conditions.

3.1.4 Buildings

3.1.4.1 Main Building

The main building is to house the administrative offices, chemical laboratory, the instrument shop, main switchgear, central control room, and adequate sanitary and shower facilities for the occupants.

The entire building is to be pressurized to about 2.5 mm (0.1 in) of water. Adequate air conditioning equipment is to be provided for the building. Heat pumps are to be considered for heating and air conditioning purposes.

The chemical laboratory is to be provided within the confines of the main building. This laboratory is to be equipped in such a manner that those routine chemical analyses required to control the quality of the various waters used within the plant can be performed. The laboratory must also contain the equipment necessary for performing analysis on the ammonia received, both in storage and in the energy conversion system.

3.1.4.2 Shop Building

A prefabricated shop building is to be provided to perform normal maintenance functions. The building shall be fully air-conditioned and shall include instrument/electrical shop, machine shop/tool room, general maintenance/welding area, spare parts and supplies storage area, and washroom/shower facilities.

3.2 MECHANICAL

3.2.1 Heat Engine

The heat engine selected for this demonstration plant is a Rankine cycle with ammonia as the working fluid. A schematic of the basic Rankine cycle power plant is shown in Figure 6. The ammonia is heated, vaporized, and superheated in a series of heat exchangers by hot brine from the solar pond. It

FIGURE 6. Solar Pond Power Plant System Flow Diagram

is then expanded through a turbine-generator to produce electricity. To close the cycle, ammonia is condensed at low pressure and then pumped back up to pressure by the feed pump.

3.2.1.1 General Description

The specific cycle design points of the heat engine for this facility were optimized using the GCOST computer code. GCOST simulates the production of electricity from thermal energy collected in a solar salt pond and calculates the potential cost of the solar thermal power. For this study it was assumed that the thermodynamic design could be defined by a set of important parameters. By selecting one set of parameters, a given cycle was defined and GCOST was used to calculate average annual performance, plant capital cost and, finally, levelized energy cost. Though the GCOST model is centered around the heat engine, it is important to note that it also computes the effects of design parameters on solar and evaporation pond costs and piping costs.

The parameters used to define the power cycle are the working fluid, the vapor generator approach, vapor generator pinch point, condenser approach, and condenser range temperatures. For a particular set of temperatures, the choice of working fluid determines the state point pressures, the required flow rates, and the cycle efficiency. In addition, the heat transfer properties of the working fluid affect the heat exchanger design. The four temperature parameters are illustrated in Figure 7. A small approach temperature difference implies large vapor generator, preheaters, and condensers, but results in an efficient cycle due to the high working fluid temperature at the turbine inlet and the low working fluid temperature in the condenser. A high approach temperature difference results in small less costly heat exchangers but a relatively inefficient power cycle.

Varying the vapor generator approach temperature difference is significant because the corresponding variations in cycle efficiency result in variations in solar pond size; therefore, the cost of the vapor generator is traded off against the cost of the solar salt pond. Varying the condenser approach temperature difference results in a similar tradeoff between condenser cost and solar salt pond size.

FIGURE 7. Definition of Heat Engine Parameters

In addition to affecting the size of the vapor generator, the pinch point temperature difference determines the brine flow rate. This results in trading off brine piping and pumping power costs versus heat exchanger cost. Similarly, the condenser range determines the cooling water flow rate, which allows a trade-off of cooling water pumping power and piping cost versus condenser cost.

Because of the low temperature of the heat source (solar pond), steam was not a suitable working fluid. Several organic and inorganic working fluids were considered during the optimization procedure including R113, R114, n-butane and ammonia. Although the thermodynamic properties of ammonia yield a lower cycle efficiency than the other fluids, this fluid was selected because its excellent heat transfer properties resulted in lower heat exchanger costs and produced the lowest LEC.

The parameters that define the selected heat engine cycle are shown in Table 3, along with key plant characteristics. In addition, the cycle state points are shown in Figure 8.

TABLE 3. Optimum Heat Engine Cycle Design

Working fluid	Ammonia
Vapor generator approach temperature, °C (°F)	8 (15)
Vapor generator pinch point, °C (°F)	4 (8)
Condenser approach temperature, °C (°F)	8 (15)
Condenser range, °C (°F)	6 (10)
Brine flow rate, kg/sec (lbm/hr)	831.4 (6.38×10^6)
Working fluid flow rate, kg/sec (lbm/hr)	47.9 ($.37 \times 10^6$)
Cooling water flow rate, kg/sec (lbm/hr)	2192 (17.4×10^6)
Net cycle efficiency	8.63
Net power output, MW _e	4.53

FIGURE 8. Power Plant State Point Conditions

3.2.1.2 General Equipment Requirements

The system flow diagram (Figure 6) only includes the major components of the heat engine. In addition to these major components, the design by the architect-engineering firm shall include a knockout drum to insure dry vapor at the turbine inlet and an accumulator to accommodate volume changes during load variations and to provide for ammonia storage during shutdowns. In addition, any component that is deemed necessary for the efficient operation of the plant or the protection of personnel or equipment shall be included in this design. Adequate valving will be provided for the operation and control of the plant. An ammonia bypass line around the turbine and any other lines or valves required for startup and shutdown are to be provided. Means for quick shutoff of ammonia flow to the turbine during emergency conditions is to be provided in order to protect personnel and equipment. A quick-closing emergency trip valve is to be supplied by the turbine manufacturer for that purpose. Isolation valves and bypass lines are to be provided around major components for maintenance.

All piping, heat exchangers, and vessels shall be protected from over-pressure by adequately-sized relief valves that discharge to the waste aqueous ammonia tank for the ammonia system and to appropriate drains for the brine and cooling water systems. Check valves will prevent return of the waste fluids to the system.

A nitrogen system for purging the air or ammonia vapor from the working fluid lines is to be provided. Connections for purging and venting the low pressure ammonia vapor from the lines and equipment during shutdown and evacuation are to be provided at appropriate points in the piping system. Piping configurations are to be designed to minimize entrapment of ammonia within the equipment and to expedite venting and purging. These purge lines will have solenoid-operated valves and will be combined into a common line. This line will terminate at an aqueous ammonia tank located near the ammonia storage facility. Here the waste ammonia being carried with the impurities will be introduced into water or a weak ammonia solution where it will be dissolved. The resulting aqueous ammonia can be either discarded or sold for fertilizer.

Pressurized ammonia storage vessels and a tank truck unloading station will supply and store an inventory of liquid ammonia for the test facility. The storage tanks will be located adjacent to a paved road. A fill pump will pump liquid ammonia to the system. The location and orientation of the tanks will facilitate offloading of anhydrous ammonia from rail cars on the plant siding, or from tank trucks. Connections will be provided to pump from either a truck or railroad car.

All pressure vessels for the power plant will be designed, manufactured, and tested in accordance with the ASME boiler and pressure vessel code. All heat exchangers are to be designed, manufactured, and tested in accordance with all applicable codes and standards. All transformers, switchgear, and controllers for the electrical system are to be designed, manufactured, and tested in accordance with applicable sections of ANSI and NEMA standards.

The specific heat engine layout and equipment arrangement has not been specified in this report and is the responsibility of the architect-engineering firm. In designing a plant layout, two areas deserve special consideration:

- 1) Minimize fluid pressure losses. This consideration applies to the working fluid, brine and cooling water systems, so particular care should be exercised in the design of water passages, and piping diameters, lengths and configuration.
- 2) Construction, operation, and maintenance consideration. Necessary free space is to be provided for the maintenance and/or replacement of all components (heat exchanger tube bundles, etc.). Adequate space for the maneuvering of heavy lifting equipment, such as mobile cranes, is to be provided.

3.2.1.2.1 Vapor Generator

Heat exchangers represent a major fraction of the cost of the heat engine and, as such, the design of the heat exchangers would be optimized as much as possible. Although the thermodynamic cycle state points of the system were optimized within the systems optimization study, and should be adhered to in the design, the heat transfer coefficients and heat exchanger areas are to be used as guidelines only.

The vapor generator system is made up of three heat exchangers (or banks of heat exchangers) to perform three different functions. First, the working fluid is heated to the saturation temperature in the preheater, then it is boiled in the vaporizer, and finally it is superheated in the superheater.

While the temperature, pressure, flow rate, and thermal load are specified for each heat exchanger in this report (Tables 4-6), the physical configurations are not specified and are the responsibility of the architect-engineering firm. The heat exchangers designed for this power plant shall be of the conventional shell-and-tube type. Because the limiting heat transfer occurs on the brine side, the brine will flow through the tubes and the working fluid will be on the shell side in all three cases, unless adequate justification for inverting this configuration can be presented by the Architect-Engineer. The heat exchanger configuration (i.e., one large heat exchanger or multiple smaller units in parallel, number of passes, etc.) will be at the discretion of the designer. Consideration should be given to the economics of design and fabrication of the units, as well as to the transportation and erection of the units (trading off factory versus field erection) when deciding the heat exchanger configuration. The heat exchanger designs are to be finalized through contact with heat exchanger manufacturers. At least one design and quote are to be provided for each heat exchanger unit. All applicable codes and standards are to be used in their design, manufacture, and testing.

Because of the novel combination of unusual working fluid and low temperature differences, heat transfer coefficients are particularly difficult to estimate. Although these coefficients (and corresponding log mean temperature differences and heat transfer areas) are included in Tables 4-6, these values are intended to be used only as guidelines. It is expected that the architect-engineering firm (or heat exchanger manufacturer) may, given adequate justification, modify these specifications as necessary. If reliable data on coefficients for this fluid and temperature range are not available, the ones presented in the report can be used for preliminary design purposes.

TABLE 4. Heat Exchanger Specifications

Service: Preheater

	<u>Shell Side</u>	<u>Tube Side</u>
Fluid	Liquid Ammonia	Brine
Fluid flow rate, kg/sec (lbm/hr)	47.9 ($.38 \times 10^6$)	831.4 (6.6×10^6)
Temperature in, °C (°F)	27.3 (81.1)	72.8 (163.1)
Temperature out, °C (°F)	68.4 (155.2)	70.1 (158.2)
Operating pressure, kPa (psia)	3200 (464)	207 (30)
Heat exchanged, kW (Btu/hr)	9596 (32.75×10^6)	
Overall heat transfer coefficient, W/m ² °C (Btu/hr ft ² °F)	1444 (254.3)	
Log mean temperature difference, °C (°F)	16.9 (30.4)	
Heat transfer area, m ² (ft ²)	392 (4218)	
Construction material	Carbon Steel	

TABLE 5. Heat Exchanger Specifications

Service: Vaporizer

	<u>Shell Side</u>	<u>Tube Side</u>
Fluid	Vaporizing Ammonia	Brine
Fluid flow rate, kg/sec (lbm/hr)	47.9 ($.38 \times 10^6$)	831.4 (6.6×10^6)
Temperature in, °C (°F)	68.4 (155.2)	85.5 (185.9)
Temperature out, °C (°F)	68.4 (155.2)	72.8 (163.1)
Operating pressure, kPa (psia)	3200 (464)	207 (30)
Heat exchanged, kW (Btu/hr)	44,369 (151.43×10^6)	
Overall heat transfer coefficient, W/m ² °C (Btu/hr ft ² °F)	1121 (197.4)	
Log mean temperature difference °C (°F)	9.3 (16.8)	
Heat transfer area, m ² (ft ²)	4215 (45364)	
Construction material	Carbon Steel	

TABLE 6. Heat Exchanger Specifications

Service: Superheater

	<u>Shell Side</u>	<u>Tube Side</u>
Fluid	Ammonia Vapor	Brine
Fluid flow rate, kg/sec (lbm/hr)	47.9 ($.38 \times 10^6$)	831.4 (6.6×10^6)
Temperature in, °C (°F)	68.4 (155.2)	86.0 (186.8)
Temperature out, °C (°F)	77.7 (171.9)	85.5 (185.9)
Operating pressure, kPa (psia)	3200 (464)	207 (30)
Heat exchanged, kW (Btu/hr)	1790 (6.11×10^6)	
Overall heat transfer coefficient, W/m ² °C (Btu/hr ft ² °F)	995 (175.2)	
Log mean temperature difference, °C (°F)	12.2 (21.9)	
Heat transfer area, m ² (ft ²)	148 (1592)	
Construction material	Carbon Steel	

One of the significant concerns in this power plant design is the fouling of the heat exchangers. These heat exchangers shall be designed with an allowable fouling factor of 0.0002 m²°C/W (0.001 ft²hr °F/Btu) on the brine side and 0.0001 m²°C/W (0.0005 ft²hr °F/Btu) on the ammonia side. Because of the low capacity factor, it is assumed that all required cleaning and maintenance procedures will be scheduled during plant down time without impacting plant operation. This removes the necessity for an automatic heat exchanger tube cleaning system or a redundant heat exchanger in each bank to allow cleaning during operation.

Extremely high brine flow rates (on the order of 11,650 gpm) make parasitic pumping power an important parameter in power plant design. In accordance with good design practice, the pressure drop through the heat exchangers should be low to reduce the required pumping power. For this design, the maximum allowable pressure drop through the vapor generator shall be 103 kPa (15 psi) on the brine side and 34 kPa (5 psi) on the working fluid side.

The heat exchangers must be protected from overpressure by the inclusion of adequately-sized relief valves. Each heat exchanger must include sufficient

valving to isolate it from the others. The heat exchangers shall be designed to minimize entrapment of ammonia. In addition, connections shall be provided to purge the heat exchangers with inert gas so that maintenance can be performed.

3.2.1.2.2 Turbine-Generator System

The functional criteria for the turbine-generator system are presented in this section. The turbine-generator design is to be finalized through contact with manufacturers. At least one design and quote are to be provided with this plant design.

As a part of the heat engine review, a turbine consultant was hired to review the impact of working fluid selection on the turbine design. Significant results of that work include:

- 1) Inlet and outlet conditions for each of eight fluids
- 2) Size, speed and specification of a turbine for each of the eight fluids considered
- 3) Mechanical and materials design considerations for each of the eight fluids.

Results specific to the ammonia turbine indicated that ammonia had the highest enthalpy drop, resulting in a small, high pressure, high speed machine. An acceptable outlet quality of 94% brought the thermodynamic cycle efficiency up to the other fluids. On the negative side, ammonia is toxic and flammable, and corrosive to some normal materials of construction (copper bearing alloys) and thus creates some handling problems.

The turbine-generator system is to be designed to operate as a peaking unit in a central generating station environment. There will be occasional variations in the turbine-generator load due to variations in the electrical network demand or seasonal demand. The generator system is to be designed to maintain frequency when operating as a single unit. Machine characteristics are also to be such that the unit can be operated with other generators connected into the power grid.

The turbine and generator are to be direct-connected for operation as a unit at a synchronous speed of either 1800 or 3600 revolutions per minute. If

a turning gear is required by the manufacturer, it is to be equipped for automatic starting.

The turbine-generator and auxiliary equipment are to be installed outdoors in an electrical hazard area classified Class 1, Division 2, Group D as defined in the National Electric Code. Outdoor equipment must be able to withstand ambient air temperatures of 49°C (120°F) and sun radiation heat to 82°C (180°F).

All parts of the turbine-generator are to be accessible and removable for maintenance. Major turbine-generator components are to be arranged in such a manner that a gantry crane can be utilized during maintenance.

The equipment and structural anchors are to be capable of accommodating the seismic acceleration levels established for the area in addition to normal operating forces.

The turbine-generator is to be designed to limit sound levels to 90 dBA or less, as measured at a distance of 3 ft. from any projection of the unit or from any enclosure.

Components are to be subjected to various tests at the factory. Such tests are to include, but not be limited to:

- Overspeed rotor assemblies
- Hydrostatic tests
- High potential test of stator and armature assemblies
- Four-hour mechanical run of turbine and accessories

The components of the turbine-generator are to be inspected during the manufacturing and assembly processes by purchaser inspectors and quality assurance personnel to ensure compliance with specifications and applicable standards.

The turbine-generator is to be guaranteed by the manufacturer for capacity and performance in accordance with specifications. In addition, the vendor is to warrant the unit against incorrect designs, defective materials, poor workmanship, and failure from normal usage for a specified period of time. The system is to be designed to accommodate and control load changes created by the variations in the brine system flow during startup and normal

operation. The system is also to be designed to accommodate instantaneous interruption of the ammonia flow to the turbine under full load operation or upset conditions.

The ammonia turbine designed for this power plant will be a small, high-speed expander. The specifications for this unit are given in Table 7. The turbine may be an axial flow or a radial in-flow machine. A single inlet nozzle with downward-oriented exhaust nozzles is the most desirable arrangement. The casing is to be either cast or fabricated steel and all split lines are to be leakproof. The rotor may be either "stiff" or "flexible" shaft design.

TABLE 7. Turbine Specifications

Gross output (MW)	5
Turbine inlet pressure (kPa)	3,200
Turbine outlet pressure (kPa)	1,080
Ammonia mass flow rate (kg/sec)	47
Isentropic enthalpy drop (kJ/kg)	106
Turbine wheel diameter (cm)	46
Shaft speed (rpm)	13,500
Isentropic efficiency (%)	80
Outlet quality (%)	94.3
Outlet mach number	0.23
Number of stages	1
Gear reduction required?	Yes
Material of construction	Steel

The shaft sealing design is to prevent leakage of ammonia to the atmosphere, even when the shaft is at rest and the turbine casing is under pressure. In the event oil is employed for the shaft sealing system, the seal oil system is to be capable of recovering seal oil liquid for recycling and collecting ammonia vapors for disposal. A buffered gas shaft seal arrangement is also acceptable. This system is also to be capable of collecting ammonia leakage and buffering gas for disposal.

Turbine shaft seal leakage is to be vented to the ammonia collection system. Various types of sealing systems are available and final determination of recycling arrangements must await selection of a specific turbine supplier. The ammonia collection system is to be designed to dispose of any ammonia recovered from the sealing oil or the buffer gas required by the turbine manufacturer.

3.2.1.2.3 Condenser

The condenser serves to return the ammonia to a liquid state after it exits the turbine. Water from the Great Salt Lake shall be used for condenser cooling. The surface-type condenser shall be of conventional design with the spent vapor from the turbine entering at the top and flowing through the condensing area in a downflow configuration. The specifications for the condenser are given in Table 8. As with vapor generator specifications, the heat transfer coefficient, heat transfer area, and log mean temperature difference are intended as guidelines only, pending further investigation.

TABLE 8. Heat Exchanger Specifications

Service: Condenser

	<u>Shell Side</u>	<u>Tube Side</u>
Fluid	Condensing Ammonia	Cooling Water
Fluid flow rate, kg/sec (lbm/hr)	47.9 ($.38 \times 10^6$)	2192 (17.4×10^6)
Temperature in, °C (°F)	27.2 (81)	18.9 (66)
Temperature out, °C (°F)	27.2 (81)	24.4 (76)
Operating pressure, kPa (psia)	1,076 (156)	207 (30)
Heat exchanged, kW (Btu/hr)	50,970 (173.96×10^6)	
Overall heat transfer coefficient, W/m ² °C (Btu/hr ft ² °F)	1,642 (289.3)	
Log mean temperature difference, °C (°F)	5 (9.1)	
Heat transfer area, m ² (ft ²)	6.139 (66,077)	
Construction material	Carbon Steel	

As with the vapor generator, the condenser configuration (number of units, number of passes, etc) is the responsibility of the architect-engineering

firm or heat exchanger manufacturer. One large condenser would probably be the optimum from a fabrication cost standpoint. Vapor transport and distribution problems associated with large diameter shells, however, may indicate multiple smaller condensers. The configuration is to be finalized through contact with potential manufacturers. At least one condenser design and quote is to be provided with the plant design.

The condensers are to be manufactured with carbon steel shells, tubes, and water boxes of lined carbon steel. These condensers are to be of the shell and tube type with internal vapor inlet distribution. The hot wells are to be designed to store approximately one minute of condensate flow.

Pressure losses incurred after the working fluid is exhausted from the turbine are critical to overall plant efficiency and must be minimized by proper design of the condenser and the interconnecting piping between the turbine and condenser. The maximum allowable pressure drop on the cooling water side will be 103 kPa (15 psi), and on the ammonia side, 34 kPa (5 psi). The ammonia pressure on the shell side will exceed the cooling water pressure in the tubes. The tube/tube sheet joint and the tubes are to be designed to minimize the risk of leakage of ammonia to the water and, subsequently, to the Great Salt Lake.

The condenser shall be protected from overpressure by including adequate relief valves. It shall be designed to minimize the entrapment of ammonia liquid or vapor and connections shall be provided for the purpose of purging the working fluid side with inert gas. The fouling of the condenser will occur primarily on the cooling water side (in the tubes). The maximum allowable fouling factor shall be $0.0002 \text{ m}^2\text{C/W}$ ($0.001 \text{ ft}^2\text{hr } ^\circ\text{F/Btu}$) on the cooling water side and $0.0001 \text{ m}^2\text{C/W}$ ($0.0005 \text{ ft}^2\text{hr } ^\circ\text{F/Btu}$) on the ammonia side.

3.2.2 Piping System

Previous studies (SERI Truscott Brine Lake Task Force, 1981, ORMAT Turbines, 1981) indicated that piping represents a major component of the solar pond power plant capital cost. In order to minimize the expenses associated with piping, the piping systems were designed using the ETRANS computer code (Barnhart, 1980). This section describes the optimization technique and the resulting piping systems.

3.2.2.1 Optimization Technique

The goal of the piping optimization task was to select the pipe size and insulation thickness which would minimize the costs associated with the piping. The ETRANS code is designed specifically to select piping and insulation for solar thermal applications. The optimization procedure consists of analyzing the costs associated with a range of discretely sized pipe, each with a variety of insulation thicknesses. The combination of piping size and insulation thickness which produces the lowest life-cycle cost was then selected. The figure of merit was levelized energy cost, which included both the amortized capital cost of the pumps and piping and the operating costs associated with pumping power and thermal losses where appropriate. Of vital importance in the optimization is the cost assigned to the pumping power. A low cost will produce an optimized design with small piping and high pumping power. In this study, it was assumed that the solar pond power plant provided the pumping power; therefore, the cost of pumping power should approximate the levelized energy cost of power produced by the solar pond power plant. All piping was assumed to have a life of 20 years.

The results of the piping optimization study include approximate sizes for each run of piping (excluding working fluid piping which is costed in the heat engine optimization). Pumps were sized and costed on the basis of the flow rates and pressure drops estimated for each system. In addition, one spare pump was included in each system to improve reliability (e.g., (3) 50% capacity pumps on the hot brine system). Only the hot brine transport piping required insulation; the optimal thickness was 3.8 cm.

The large impact of pumping power cost on piping selection suggests that it is not appropriate to use pipe sizing rules of thumb developed for low-cost energy sources. In particular, the use of design velocities developed for steam power plant and refinery design may be based on low estimates for pumping power costs which would produce non-optimum designs with undersized piping and excessively high pumping power.

The low capacity factor of the plant also affected piping selection because of the limited running time. To some extent this mitigated the impact

of high pumping power costs; as running time decreases, capital expenses begin to dominate the life-cycle cost and smaller pipe sizes become cost-effective.

3.2.2.2 Piping System Description

The piping layout was designed after the preliminary plant arrangement was developed. The major piping systems include:

- Brine Piping - The brine piping includes the piping required to extract brine from, and return it to, the storage zone. Hot brine is withdrawn from the storage zone through a system of inlet diffusers manifolded together. The brine is pumped to the power plant where heat is extracted in the vapor generator. The cooler return brine is injected into the storage zone through a series of outlet diffusers which are manifolded together. The brine piping is assumed to be fabricated from carbon steel. The inlet and outlet diffusers were based on the linear design model tested by the U.S. Army Corps of Engineers (Bohan, 1973). Details of the brine piping are shown in Figure 9.
- Cooling Water Piping - The power plant is assumed to be cooled by water taken from the Great Salt Lake. Due to the low conversion efficiency of the heat engine, the heat rejection load is quite large, requiring a high cooling water flow rate. Water is removed from the Great Salt Lake, pumped through the power plant's condenser, and returned to the lake. Due to the level of dissolved oxygen in the water, fiberglass-reinforced plastic (FRP) piping should be used in place of carbon steel. Details of the cooling water piping are shown in Figure 10.
- Brine Makeup Piping - Brine makeup piping consists of the piping required to provide concentrated makeup brine to the solar pond. Piping runs from the Great Salt Lake to the evaporation pond and from the evaporation pond to the brine return piping are included. Due to the high oxygen content of the brine, FRP piping was specified. Details of the makeup piping are shown in Figure 11.
- Surface Flushing Piping - The surface flushing piping supplies fresh water for flushing the solar pond's surface and removes the brine flushed from the surface. The fresh water piping includes diffusers to spread

SECTION	DIAMETER		LENGTH	SYMMETRY	TOTAL
	(in.)	(cm)	(M)	FACTOR	LENGTH (M)
①	20	(47.8)	844	1	844
②	16	(38.1)	209	2	418
③	12	(30.3)	195	4	780
④	12	(30.3)	195	4	780
⑤	16	(38.1)	209	2	418
⑥	18	(42.9)	10	1	10
⑦	12	(30.3)	6	3	18

MATERIAL: CARBON STEEL

PUMPS: 3, 50% CAPACITY

BRINE FLOW RATE: 44,100 LIT./MIN.

PRESSURE DROP: 248 KPa

FIGURE 9. Hot Brine Transport Piping

SECTION	DIAMETER		LENGTH	SYMMETRY	TOTAL
	(in.)	(cm.)	(M)	FACTOR	LENGTH (M)
①	20	(47.8)	6	3	18
②	36	(87.6)	100	1	100
③	36	(87.6)	100	1	100

MATERIAL: FIBERGLASS REINFORCED PLASTIC
 PUMPS: 3, 50% CAPACITY
 COOLING WATER FLOW RATE: 120,000 LIT./MIN.
 PRESSURE DROP: 20 KPa

FIGURE 10. Condenser Cooling Water Piping

SECTION	DIAMETER		LENGTH	SYMMETRY	TOTAL
	(in.)	(cm)	(M)	FACTOR	LENGTH (M)
①	8	(20.3)	5	2	10
②	10	(25.5)	100	1	100
③	8	(20.3)	200	2	400
④	6	(20.3)	195	4	780

MATERIAL: FIBERGLASS REINFORCED PLASTIC

PUMPS: 2, 100% CAPACITY

FLUSHING WATER SUPPLY FLOW RATE: 4334 LIT./MIN.

PRESSURE DROP: 28 KPa

FIGURE 11. Flushing Water Supply Piping

the fresh water over the surface of the pond. The brine removal piping removes low concentration brine from the surface of the opposite side of the pond. The brine is then returned to the lake rather than recycled. This is because the salt concentration of the removed surface brine is well below the lake salt concentration and not worth concentrating for makeup. Note that the flushing water is currently assumed to be provided from the impoundment basin of the AMAX Corporation through the west canal, and drained to the Great Salt Lake. If at some future time prior to pond filling, it is deemed necessary to conserve water, the flushing water could be recycled. This would require a redesign of the salt concentrations of the gradient and storage zones to maintain a stable pond. Details of the surface flushing piping, assumed to be fabricated from carbon steel, are shown in Figures 12 and 13.

It was assumed that brine extraction and removal piping could be run through the pond rather than along the dikes. This arrangement minimizes the length of the large brine piping, but it would complicate piping maintenance if maintenance was required. Due to the uncertainties introduced by the surrogate site and preliminary site arrangement, the actual piping layout was not extensively optimized. The layout and piping system designs presented here were developed for the purpose of cost estimating and optimization of the power plant. It is expected that the actual piping design will be a cooperative effort between the Architect-Engineer and PNL.

3.3 ELECTRICAL

3.3.1 Generator

The generator is to be a 4.15 kV, 3-phase, 60-Hertz machine capable of developing full load with a 0.85 power factor and 207 kPa (30 psia) hydrogen pressure. The gas cooler arrangement must permit operation at 80% of rated kVA when one section of the coolers is shut down. The bearings are to be friction-type sleeves or a tilting pad arrangement.

The generator is to be matched to the turbine physically and functionally and is to be hydrogen-cooled. Windings are to be wye-connected and grounded through a distribution transformer with secondary resistance.

SECTION	DIAMETER		LENGTH	SYMMETRY	TOTAL
	(in.)	(cm)	(M)	FACTOR	LENGTH (M)
①	6	(15.4)	195	4	780
②	8	(20.3)	200	2	400
③	8	(20.3)	2	1	2
④	6	(15.4)	6	2	12
⑤	10	(25.5)	100	1	100

MATERIAL: FIBERGLASS REINFORCED PLASTIC

PUMPS: 2, 100% CAPACITY

FLUSHING WATER DRAIN FLOW RATE: 3140 LIT./MIN.

PRESSURE DROP: 20 KPa

FIGURE 12. Flushing Water Drain Piping

SECTION	DIAMETER		LENGTH	SYMMETRY	TOTAL
	(in.)	(cm)	(M)	FACTOR	LENGTH (M)
①	3	(7.8)	6	2	12
②	4	(10.2)	100	1	100
③	2	(5.3)	6	2	12
④	3	(7.8)	100	1	100

MATERIAL: FIBERGLASS REINFORCED PLASTIC

PUMPS: 2, 100% CAPACITY FOR MAKEUP FROM GREAT SALT LAKE

2, 100% CAPACITY FOR MAKEUP FROM EVAPORATION POND

MAKEUP BRINE FLOW RATE (FROM GSL): 473 LIT./MIN.

MAKEUP BRINE FLOW RATE (FROM EVAP. POND): 212 LIT./MIN.

PRESSURE DROP: 28 KPa

FIGURE 13. Cool Brine Transport Piping (Makeup)

A static excitation system is to be provided. If the system requires the use of collector brushes on the generator shaft, the rigging must be suitable for installation in an area designated Class 1, Division 2, Group D for electrical hazards.

The lube oil system may include a shaft-driven main pump, an ac motor-driven auxiliary pump, and a dc motor-driven emergency pump. The lube oil console is to be baseplate-mounted for installation as an assembled unit.

Generator tests specified in Table 3 of ANSI Standard C50.13 are to be conducted in accordance with IEEE Publication No. 115.

3.3.2 Substation

The substation shall be of the standard 3-phase type, and must comply with all National Electrical Code (NEC) standards. In addition, utility requirements such as primary voltage and other special requirements must also be considered in the substation design to ensure proper interface between the power plant and the electric utility distribution system.

3.4 CONTROL, INSTRUMENTATION, AND ALARMS

3.4.1 Control

The power plant control system can be divided into two major subsystems:

- a) Control of the heat supply systems (i.e., hot brine pumps and cold water pumps).
- b) Control of the working fluid systems.

The flow rate and temperature of the brine entering the power plant heat exchangers is determined in accordance with the electricity demand and the pond conditions. It is to be assumed that the SPPP is connected to a relatively large grid; therefore, no immediate response to change in demand is anticipated and the plant will work continuously at nominal 5MW output. Adjustments and setting of the brine and cold water pumping systems for optimizing heat removal from the pond can, therefore, be done by a plant operator.

Control of the turbine and other working liquid systems is designed to permit operation of the turbine at its best efficiency under different hot

brine characteristics and heat exchanger conditions. This is achieved by controlling the degree of turbine admission. Working fluid flows and levels at the different component parts of the system are also controlled.

Control room panels are to be highly visible and easily operated by the attending personnel. The control system is to be designed to ensure that all control activities that can be initiated in the control room can also be initiated from the corresponding local station. The central control panel is to be a shop-fabricated freestanding design utilizing the "medium-to-high-density" concept of instrument spacing.

The layout of the front of the panel is to be in accordance with good engineering practice with proper consideration given to accessibility for maintenance and operation. The general arrangement is to be in accordance with the following instructions:

- Alarms and indicators are to be placed in the top section.
- Controllers, recorders, and indicators are to be placed in the middle section.
- Electrical equipment controls, comprised of pushbuttons, running lights, etc., are to be placed in the lower section (or bench portion) of the panel.

Local panels are to be generally of the vertical-type design and are to be suitable for unprotected outdoor installation. All devices mounted on local panels are to be watertight and the panel design is to provide the necessary dust protection. Local start and stop pushbuttons are to be mounted on local panels.

3.4.2 Instrumentation

Instrumentation and control systems are to be provided to monitor and control the operation of the power plant. Although additional instrumentation and data acquisition capability will be required to thoroughly evaluate equipment and system performance during the demonstrative phase of operation, this experimental instrumentation will not be estimated in the current package.

In order for the different controls to operate, the following parameters should be measured:

- Pressures (working fluid, hot brine, cooling water, air)
- Temperatures (working fluid, hot brine, cooling water)
- Flow rates (hot brine, cooling water, working fluid)
- Liquid levels
- Turbine frequency
- Electrical output (frequency, voltage, power, etc.)
- Vibrations

The following criteria apply to various classifications of measurements.

Pressure Measurement

Ranges for pressure transmitters are to be in accordance with the process control requirements and are to be selected so that the normal pressure will be indicated or recorded between 50% and 75% of the span. Suppressed ranges are to be used on transmitters and controllers when maximum accuracy and control are required. Instruments are to have overrange protection to the maximum pressure to which they may be exposed.

Temperature Measurement

Thermocouples are preferred for measuring process temperatures. The use of sheathed thermocouples is most desirable, but other types may be used when necessary.

Resistance temperature detectors are to be used for applications requiring higher accuracy than is available from thermocouples in the measurement range of -150°C to $+500^{\circ}\text{C}$ (-238°F to 932°F). Resistance temperature detectors are also preferred for differential temperature measurement.

Flow Measurement

Energy conversion system flow instruments of the differential head-type utilizing a low permanent pressure loss annular primary element are preferred. Other types of primary flow elements are to be considered in accordance with the situation and economics involved.

Level Measurement

Differential pressure (D/P) transmitters are preferred to measure liquid level. External, displacer-type transmitters or controllers may be used where

D/P devices are not practical. Float-type external level switches are preferred for alarms and shutdowns.

Speed Instrumentation

Speed transmitters are to be of the "noncontact," magnetic pickup-type.

Vibration of Mechanical Equipment

Continuous vibration monitoring (both radial and axial) and associated shutdown systems are to be installed on all critical rotating equipment.

Ammonia Vapor Detection

Suitable ammonia vapor detectors will be provided in the tank truck off-loading area and the NH₃ hotwell pit. The type and sensitivity of these detectors will be determined later. They will be capable of sounding a local alarm and activating an annunciator and alarm on the facility control board.

3.4.3 Alarms

A subdivision of the power plant instrumentation and control system is the emergency control and alarms. The power plant immediately shuts down to prevent damage to personnel or equipment owing to a variety of failures, including:

- Turbine overspeed
- High level of vibration
- Overvoltage
- Overload
- Mains failure

An alarm system informs the operator in the control room of the need for intervention due to abnormal operation or component malfunction. A delay in the intervention will not cause damage to personnel or equipment, but rather cause an automatic plant shutdown.

Trip circuits and bypasses for testing are to be provided to protect the plant system against damage during emergency conditions. Deviation and absolute value alarm circuits are to monitor critical functions and energize alarms to warn operators of impending difficulties. The alarm system is to

incorporate "first out" features in order to rapidly identify the cause of a trip-out situation.

Conditions to be signalled by an alarm are classified as follows:

- Critical--Conditions that can create personnel hazards, damage major equipment or cause environmental pollution.
- Guides--Conditions that must not exceed established limits for a specified period of time.

Both visible and audible alarms are to be provided in an annunciator system. After the audible alarm has been silenced, the visible alarm is to remain until the abnormal condition is corrected.

4.0 OCCUPATIONAL AND ENVIRONMENTAL SAFETY

It is recognized that there are potential safety hazards associated with the operation of the solar salt pond facility. Through prudent engineering and design, using accepted and proven practices and experience for handling ammonia, and by invoking strict administrative controls during operation, these risks can be minimized.

The codes and standards identified in previous sections will ensure adequate safety with regard to conceptual design. The design criteria will require features to provide personnel safety and to prevent fire, high wind, or earthquake loss.

Routine audits will be conducted during operation to insure that procedures are not violated and safety limits are not exceeded.

5.0 SECURITY

No special security measures will be required during construction or operation. All facilities should be located within a chain link fence to limit access through prescribed gates only. The facility is to be adequately lighted to discourage intruders, especially during construction.

6.0 QUALITY ASSURANCE

To assure that the functional criteria and integrity of this project are completely satisfied, the design and construction of this test facility shall be controlled in accordance with Quality Assurance (QA)/Quality Control (QC) procedures developed by the Architect-Engineer (AE)/Construction Management Firm responsible for those tasks.

The Architect-Engineer will determine the level of quality assurance control required to prudently insure the safe and successful operation of the SSP Facility. In developing the QA/QC plan, the AE will apply those standard practices and procedures that are commensurate with the requirements of this project and the inherent risk associated with the failure of a system or component.

Operation planning and operation of the facility will be controlled in accordance with procedures developed by Battelle-Northwest (BNW) and guidelines provided by BNWL-MA-65, "Battelle Quality Assurance Manual."

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