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U.S. ATOMIC ENERGY COMMISSION

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OFFICE OF SALINE WATER

Evaporator Component Development Program

DEAERATOR EJECTORS AND BLOWERS FOR 50-Mgd AND LARGER DESALINATION PLANTS

S. C. Jacobs
B. E. Mitchell
R. K. Sood

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Final Report

OCTOBER 1967

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1.0 SUMMARY

In the design and the operation of seawater evaporators, care must be taken to prevent accumulations of noncondensable gases that can blanket condenser surfaces, interfere with efficient heat transfer, and cause corrosion of the evaporator internals. In a 50-Mgd flash evaporator plant which uses acid feed treatment, the designer must provide means for removing between 108,000 and 263,000 lb/day of gases which contain about 60% water vapor. A plant with an atmospheric decarbonation will be near the low end of this range.

Flow sheets were prepared for a number of systems containing blowers, ejectors, surface condensers, barometric condensers, and decarbonation ponds.

Detailed design calculations were made to determine the functional specifications for each of the components in each system. These specifications were conveyed to more than twenty leading manufacturers to obtain reliable estimating prices. While the cost estimates received had some discrepancies, they were evaluated and reconciled very carefully to arrive at a reasonable cost basis. Based on these prices and on the OSW ground rules for utility (steam, electric power) costs, an economic evaluation was made of all the different systems under consideration. This study indicates that a two-stage blower system with barometric condensers is the most economical arrangement. The cascade type (high head loss) decarbonation pond considered in this study is uneconomical; however, a low head loss pond might be useful if it worked effectively.

The evaluation of a large number of alternative materials led to the conclusion that the ejector and blower systems must be constructed of premium materials such as stainless steel, titanium, or Hastelloy C because of the highly corrosive environment.

At the request of the OSW, an addendum was made to this study to review designs of noncondensable removal systems presented in the fifteen OSW 50-Mgd conceptual plant designs. These reports clearly indicate that the general design philosophy of removing noncondensables has not been standardized. The areas of disagreement include type and size of equipment, materials of construction, amount of air inleakage, steam requirements for ejectors, and the number of ejector stages required in series.

2.0 CONCLUSIONS

This study has demonstrated that equipment of the required size, and of materials with an expected life of thirty years in a desalination plant, is available only as special equipment. Experience with the fabrication of premium materials required for this service is not readily available.

The economic evaluations, based on equipment which can be purchased now, have led to the following conclusions:

1. A two-stage blower system with barometric condensers is the most economical centralized station arrangement for 50-Mgd plants. Difference in cost between a three-stage ejector system and a two-stage blower system is small.
2. The optimum number of stages for blowers is two because the capital cost for additional stages rises faster than the savings in energy.
3. The optimum number of stages for ejectors is three, since the steam consumption is considerably less than in a two stage ejector, while only a small additional efficiency is introduced in a four-stage ejector.
4. A precondenser should be used to reduce the amount of water vapor to be evacuated.
5. Barometric precondensers and inter-condensers are preferred to surface condensers because of lower capital cost, less severe service for materials, less use of cooling water, and significant reductions in pumping power because of lower pressure drop. These factors more than offset the condensate which might be saved.
6. A cascade type (high head loss) decarbonating pond used in this study proved to be uneconomical. However, a degassing pond of the low head loss (weir) type may prove to be economical, and it might be considered in future conceptual design studies.
7. Premium materials are required. Type 316 stainless steel should be useful up to 150°F - 200°F. Hastelloy C is recommended for parts exposed to higher temperatures. The use of coatings, such as Heresite, over less costly materials is also attractive.
8. The economic evaluations reported here should be reviewed for applications with substantially different ground rules or energy costs (see Appendix A), or if more efficient ejectors become available.

3.0 INTRODUCTION

In the design and the operation of seawater evaporators, care must be taken to prevent accumulations of noncondensable gases that can blanket condenser surfaces, interfere with efficient heat transfer, and cause corrosion of the evaporator internals. These gases can enter an evaporator by being released from solution in the seawater

makeup stream and also by leakage into stages operating at subatmospheric pressure. Contributing to the dissolved gas content is the sulphuric-acid scale-control treatment, which releases substantial quantities of carbon dioxide from the seawater. Although this carbon dioxide can be removed in an open pond or a stripping tower, additional deaeration must be performed before the seawater enters the evaporator in order to lower the level of noncondensables to an acceptable value. The gases released in the deaerator and any air which leaks into the subatmospheric evaporator stages must be removed by a suitable evacuation system.

In the majority of existing desalination plants, the evacuation systems are equipped with steam-driven ejectors. Condenser evacuation systems for large power stations commonly utilize either two-stage ejectors or rotary pumps of a special type. Industrial experience in this field is extensive; however, the size of available equipment is small in relation to the requirements of a 50-Mgd evaporator plant. Numerous types of equipment are available to evacuate these gases, but the quantities involved and the corrosive nature of these gases complicate the problem and make the selection difficult. This document is an evaluation of various blower and ejector systems for deaerator service.

3.0 OBJECTIVES AND SCOPE

3.1 Objectives

The objectives of this study are as follows:

1. To ascertain the present state of the art of the blower and/or the ejector equipment suitable for removal of non-condensable gases from large distillation plants.
2. To evaluate the technical and economic problems in available systems.
3. If indicated, to encourage the industrial development of suitable new designs or systems which appear to hold promise of being more satisfactory mechanically and economically.

3.2 Scope

Included in the scope are the following aspects:

1. Determine the noncondensable gas removal requirements for 50- to 250-Mgd multistage flash distillation plants with typical cycles. This determination can be made with data that is available from the literature.
2. Prepare functional specifications for blower equipment or systems to cover 50-Mgd plants in both the modular and the non-modular forms.

3. Obtain designs and cost estimates from equipment suppliers for components required in gas removal stations.
4. Evaluate an encompassing range of station designs and submit a composite evaluation report to the Office of Saline Water.

4.0 EVACUATION LOADS

Two cases were selected as typical of the capacities that will be required for 50-Mgd distillation plants. On the low-capacity side, Case I is for a plant equipped with an atmospheric decarbonating pond or tower. This plant is also expected to be designed and built with extreme care and good quality workmanship so that the rate of air inleakage will be at a minimum. On the high-capacity side, Case II is for a plant where all dissolved gases are released in the deaerator. In addition, the air inleakage into the plant is assumed to be rather high. In both cases, it is assumed that the air inleakage will be evacuated along with the deaerator gases by a single system of evacuating equipment taking its suction from the lowest pressure in the evaporator system (0.9 psia).

Table I gives the gas loads that are anticipated for each of the two limiting cases. In Case I, 70% of the carbon dioxide, produced by the addition of sulphuric acid for scale control, is released in the decarbonation basin. Other gases remain unaffected through the decarbonation process and are evolved in the deaerator along with the balance of the carbon dioxide. The quantities of dissolved gases given in Table I correspond to a seawater temperature of 65°F and were obtained from the Technical Data Book⁽¹⁾. The suction pressure is representative of deaerator pressure in a typical 50-Mgd desalting plant, and the given temperature is the saturation temperature corresponding to the partial pressure of the steam in the mixture leaving the deaerator.

5.0 COMPONENT SELECTION

In the majority of existing desalination plants, the evacuation systems are equipped with steam-driven ejectors. Condenser evacuation systems for large power stations commonly utilize either steam driven ejectors or rotary-vane (liquid-sealed) type vacuum pumps. Many other types of removal equipment are being used successfully by the petro-chemical industry for various applications. Although industrial experience in this field is extensive, the size of equipment used is small in relation to the operating requirements of a typical 50-Mgd plant. The following types of evacuating equipment were investigated for use in this study:

1. Centrifugal compressors
2. Rotary-vane (liquid-sealed) vacuum pumps

TABLE I
ESTIMATED EVACUATION LOADS FOR A TYPICAL 50-MGD PLANT

	Case I (See Note 1)	Case II (See Note 2)
Deaerator pressure, psia	0.9056	0.9056
Deaerator temperature, °F	88	88
Water vapor, lb/day	62,083	156,869
Inleakage air, lb/day	200	2,400
Argon, lb/day	400	400
Nitrogen, lb/day	10,700	10,700
Oxygen, lb/day	6,720	6,720
Carbon dioxide, lb/day	28,500	85,500

Note 1. Plant with outside degassing pond and low air inleakage.

Note 2. Plant without outside degassing pond and high air inleakage.

3. Rotary lobe compressors
4. Water ejectors
5. Steam ejectors
6. Air ejectors

Preliminary investigation revealed that rotary-vane vacuum pumps of a capacity sufficient to meet the design requirements are not commercially available. This precluded further consideration of this type of equipment because attainment of reliable cost information would have been very difficult. Since coatings for corrosion protection would probably fail as a result of possible rubbing of the lobes in rotary-lobe compressors, premium materials and high maintenance suggested unsuitability of this equipment. This left the centrifugal compressors as the best choice among the rotating machinery. Figure 1 shows a typical cross section of a multistage centrifugal compressor for this service. These machines are at a very advanced stage of development and can be relied upon for years of trouble-free service.

Among the jet compressors, the steam jet ejector, shown in Figure 2, has an inherent advantage over the others. While steam is readily available from the energy plant, additional equipment would be required to supply motive fluid to drive water or air jet compressors. Aside from the additional equipment, the overall efficiency of these systems will also be lower since the electric power used to drive a water pump or air compressor must be produced by the steam from the same source as the steam used in the steam-driven ejectors. Assuming that the jet compression efficiencies of water, steam, and air are approximately equal, the steam-jet ejector is preferred to air or water jets in a distillation plant.

With these considerations, centrifugal blowers and steam ejectors have been selected as the two leading contenders for the desalination plant service, and were subjected to detailed comparative economic evaluation.

It is well-established practice to improve gas compression efficiency by dividing the compression range into several steps and by providing intermediate cooling to reduce the gas volume. After careful consideration, the range of compression was divided into a two-stage system as one of the alternatives and a three-stage system as another alternative. These systems operate on an overall compression ratio of 17.9 for the examples of this report.

There are two types of cooling equipment that may be used for this service. One is the direct contact type (barometric condenser), and the other involves heat transfer through a metal wall (surface condenser). Figures 3 and 4 show cross sections of typical barometric and surface condensers, respectively. Each type has certain advantages and disadvantages dependent upon the particular application. Table II illustrates the various equipment combinations that have been investigated.

Figure 1
THE CENTRIFUGAL COMPRESSOR
(Clark Brothers Company)

Figure 2
STEAM EJECTOR
(Elliott Company)

Figure 3
BAROMETRIC CONDENSER

Figure 4
 PROPOSED SURFACE TYPE TWO-PASS HEAT EXCHANGER
 Four-pass heat exchangers have flexible shell instead
 of flexible tube sheet.

TABLE II
EVALUATION OF DIFFERENT STATION
EQUIPMENT ARRANGEMENTS

Station Type	Stages in Series	Precooler Type	Inter-Condenser Type
Ejector	Two	Surface	Surface
Ejector	Two	Barometric	Barometric
Ejector	Three	Surface	Surface
Ejector	Three	Barometric	Barometric
Blower	Three	Surface	Surface
Blower	Three	Barometric	Barometric
Blower	Two	Surface	Surface
Blower	Two	Barometric	Barometric

In addition to the inter-condensers, a precondenser was incorporated in all cases to reduce the amount of water vapor to be pumped. After-condensers were considered in the study but did not appear to have an economic justification.

6.0 DEVELOPMENT OF ALTERNATE DESIGNS

After a decision had been reached on the type of components to be used, the next step was to establish design criteria for each type system and its component equipment.

In keeping with a design philosophy of simplicity in design and of low maintenance cost, it was decided to use single full-capacity units of equipment rather than several smaller units in parallel. This decision is further substantiated by the fact that the steam ejectors are very large, thus minimizing plugging malfunctions. Blowers can be operated for long periods with no excessive maintenance. In addition, the systems (evaporator and evacuation) can tolerate minor malfunctions for moderate periods until the next plant shutdown.

The most efficient way to divide an adiabatic gas compression process for intercooling is to split it into steps of equal compression ratios. Except for the pressure drop through the inter-condensers, the compression range of the blower systems in this study was divided into two or three steps to provide the same temperature at the inlet to each blower. In order to confine the study and to keep the comparison on an equal basis, we held the pressure ratios and the inlet temperatures for the ejectors at the same values as those for the corresponding blowers. Tables III, IV, and V are typical examples of the design conditions of operation for the evacuation equipment. The power requirements for the blowers were based on 70% adiabatic efficiency. Estimates of the steam requirements for the ejectors were confirmed by information obtained from manufacturers and by that available in literature.⁽²⁾⁽³⁾⁽⁴⁾

Consideration was also given to the temperature to which the gases should be cooled in each of the condensers. Condenser gas outlet temperatures of 75°F and 80°F were selected and the overall cost difference evaluated for both the barometric and the surface condensers. At the lower temperature, the required surface or the quantity of cooling water are larger; but at the higher temperature, the energy requirements of the subsequent ejector or blower are larger. The difference proved to be small, but it favored the 75°F value selected for this study. (Sea-water at 65°F was assumed to be available for cooling.)

In the design of barometric condensers, the minimum terminal temperature difference* was established as 8°F, and the maximum temperature of cooling water leaving the condenser was fixed at 110°F. The gas pressure drop

* Difference between the dew point temperature of the inlet gas and the exit temperature of the cooling water.

TABLE III
 LOWEST COST SYSTEM FOR EJECTORS
 3-STAGE EJECTOR SYSTEM USING BAROMETRIC CONDENSERS (CASE I)

<u>Ejectors</u>	<u>No. 1</u>	<u>No. 2</u>	<u>No. 3</u>
Inlet flow:			
Water vapor, lb/hr	941	227	77
Noncondensables*, lb/hr	1938	1938	1938
Pressure, psia	0.86	2.18	5.52
Temperature	75	75	75
Discharge:			
Pressure, psia	2.29	5.81	14.7
Temperature, °F	181	208	221
Motive steam:			
Flow, lb/hr	-----	6900 lb/hr	-----
Pressure, psia	-----	114.7	-----
Temperature, °F	-----	338	-----
<u>Barometric Condensers</u>	<u>Precond.</u>	<u>Inter-cond. No. 1</u>	<u>Inter-cond. No. 2</u>
Size (diameter), in.	21	18	18
Cooling water flow, gpm	231	160	124
Cooling water inlet temp., °F	65	65	65
Cooling water outlet temp., °F	80	110	110

* See Table I for composition.

TABLE IV

LOWEST COST SYSTEM WITH SURFACE CONDENSERS
(CASE II) USING 2-STAGE BLOWERS

<u>Blowers</u>	<u>No. 1</u>	<u>No. 2</u>
Inlet Flow:		
Water vapor, lb/hr	2200	300
Noncondensables*, lb/hr	4405	4405
Pressure, psia	0.86	3.28
Temperature, °F	75	75
Discharge:		
Pressure, psia	3.649	14.7
Temperature, °F	403	413
Brake horsepower	262	157
<u>Surface Condensers</u>	<u>Precond.</u>	<u>Inter-cond.</u>
Surface, ft ²	2070	800
Tube length, ft	17	10.6
Tube size	3/4" O.D. x 20 BWG	3/4" O.D. x 20 BWG
No. of passes	4	4
Shell diameter, in.	30	24
Cooling water flow, gpm	724	456
Cooling water velocity, fps	5	5
Cooling water inlet temp., °F	65	65
Cooling water outlet temp., °F	77	76
Overall U, Btu/hr, ft ² °F	192	38

* See Table I for composition.

TABLE V
OPTIMUM SYSTEM (CASE II)
2-STAGE BLOWER SYSTEM USING BAROMETRIC CONDENSERS

<u>Blowers</u>	<u>No. 1</u>	<u>No. 2</u>
Inlet flow:		
Water vapor, lb/hr	1968	279
Noncondensables*, lb/hr	4405	4405
Pressure, psia	0.86	3.466
Temperature, °F	75	75
Discharge:		
Pressure, psia	3.649	14.7
Temperature, °F	390	399
Brake horsepower	240	151
<u>Barometric Condensers</u>	<u>Precond.</u>	<u>Inter-cond.</u>
Size (diameter) in.	36	15
Cooling water flow, gpm	640	98
Cooling water inlet temp., °F	65	65
Cooling water outlet temp., °F	80	110

* See Table I for composition.

through the barometric condensers was considered to be negligible. After the calculation of the cooling water requirements from the total heat load, the standard size of the barometric condenser was selected from the data presented in "Standards of Heat Exchange Institute."⁽⁵⁾

The design of surface condensers proved to be complex. The problem is complicated by high percentages of noncondensables mixed with the steam. When a mixture of noncondensables and steam is exposed to a surface colder than its dewpoint, condensation occurs and forms a thin layer of liquid on the surface. Next to this layer, a film of the gas mixture is formed which is depleted in vapor and rich in noncondensables. Because of the difference in partial pressures of the vapor in this film and of the bulk stream, vapor diffuses from the main body through the film to condense on the cold surface. The rate of condensation is thus limited and governed by the laws of diffusion of vapor through a gas. Therefore, a detailed design computation was undertaken to estimate the expected condensing heat transfer coefficients for all the surface condensers under study.

The method of Colburn, Chilton, and Hougen as presented by Kern⁽⁶⁾ was utilized as the basis of calculation. This method entails the use of a bulk gas temperature, a water temperature, and an intermediate temperature at any point. The resistance to sensible and latent heat flowing across the liquid condensate layer was ignored as it was expected to be very small compared to the resistance offered by the gas film. Since in all the heat exchangers the condensing temperature range was long and the cooling water temperature range was short with no temperature cross, very little inaccuracy resulted from assuming a true countercurrent arrangement of the fluids. Another simplifying assumption made was that the quantity of condensate dripping from the tubes that will evaporate by coming in contact with hotter gases would be negligibly small.

The calculation technique was incorporated into a small computer program. After choosing other design criteria such as terminal temperatures, flows, pressure drops, and water velocities, the computer program was run to determine the surface requirements of all the surface condensers under study.

7.0 MATERIAL SELECTION

One of the most difficult aspects of this study has been the selection of materials that are suitable in all respects. These factors include corrosion resistance, strength, and durability to give a 30-year life, material cost, ease of fabrication, and experience of prospective manufacturers in working with these materials.

The mixture of gases from the deaerator consists of oxygen, carbon dioxide, water vapor, and traces of entrained seawater containing sodium chloride. The two most versatile and cheapest materials of construction, carbon steel and cast iron, are subject to severe corrosion when in direct contact with wet carbon dioxide and oxygen.

The next best choice is stainless steel. Type 316 stainless steel is now used in many desalting plant ejector systems, and no failures have been reported to date. Considerable caution is required in the use of stainless steels in chloride-containing environments subject to wetting and drying; a considerable amount of stress corrosion cracking has been experienced in the power and nuclear industries.

Among nonferrous alloys the materials considered were Monel, Inconel, Hastelloy C, titanium, and Karbate (impervious graphite).

Although Monel and Inconel give excellent service in seawater under turbulent conditions, marine organisms may accumulate under stagnant seawater and induce local oxygen concentration cell action to cause pitting-type corrosion. Monel is also subject to corrosion under the environment of wet carbon dioxide. Fabrication limitations eliminated Karbate as the material for some parts of ejectors and heat exchangers. Hastelloy C and titanium seem to have the best potential for use in this service. Since their use is expected to increase in the coming years, the cost of these premium alloys is expected to drop in relation to other materials.

Several commercially available protective coatings were considered. Many of these coatings have given excellent service, but the life expectancy cannot be accurately predicted at high temperatures since no long-term operating data are available. However, the cost advantage of using protective coatings over use of premium materials is great, even if the coating has to be reapplied a few times during the life of the plant. For applications where the temperature is low and the conditions are not very erosive, the protective coatings probably can be used advantageously for some of the equipment under consideration. Since the cost of the coatings is a very small fraction of the total equipment cost, it will not influence the ultimate results of this study. The individual plant designer should select the best coatings available at the time of actual plant construction. However, for purposes of this study, Heresite was selected as the protective coating. It is a phenol formaldehyde synthetic resin compound.

The following materials of construction are recommended for the subject equipment:

7.1 Centrifugal Blowers

This is expensive equipment which requires precise and complex design work. Investigations reveal that the commercially available blowers of the required size are made mostly of ferrous alloys. Making blowers of special alloys would involve considerable development work. Therefore, a protective coating seems to be the best solution; it is recommended that blowers be constructed of cast iron containing 3% nickel and coated with a Heresite coating suitable for the anticipated temperature level.

7.2 Ejectors

Because of the high velocity, temperature, and erosive conditions involved, a protective coating is not expected to give satisfactory service. Furthermore, the cost of the ejector is small relative to the cost of the steam used to drive the ejector; inefficiencies induced by the wear of nozzles and diffusers are expected to reduce the efficiency of the steam jets. The most wear-resistant materials should be used for this service, namely, Hastelloy C or titanium. Type 316 stainless steel is an alternate, but there is more risk of corrosive attack.

7.3 Surface Condensers

The use of protective coatings on the tubes and in the shell is impractical. The heads can be easily coated and thus can be made of carbon steel or cast iron. Since 65°F cooling water is available and the outside film heat transfer coefficient is low due to non-condensables, the tube wall temperature will not be very high. This would suggest that stainless steel tubes could be used, although it is necessary that local hot spots be avoided.

In the cost studies reported later, Hastelloy C was assumed to be the tube material of inter-condensers; type 316 stainless steel was used for precondensers.

7.4 Barometric Condensers

Because of the highly erosive nature of falling water, coatings are not expected to last very long on those surfaces which are under the direct impact of water. However, such surfaces will remain cool because of direct contact with cooling water.

Type 316 stainless steel is recommended, but hot spots originating from the steam entry should be eliminated or a Heresite coating could be applied locally.

8.0 SYSTEMS COSTS

The original scope of this work was formulated on the assumptions that suitable equipment would be available from manufacturers and that cost information could be obtained readily from normal commercial sources. As the study progressed, it became apparent that these assumptions were over-optimistic. We contacted twenty leading equipment manufacturers and found that most of the readily available equipment prices were for carbon steel construction, while the applications required the use of premium materials. Functional specifications were forwarded to the following manufacturers to obtain design and cost information.

Acme Industries, Inc.
 Allis-Chalmers Manufacturing Company
 Clark Brothers Company
 Elliott Company
 Condenser Service & Engineering Company
 Downingtown Iron Works
 Graham Manufacturing Company
 Ingersoll-Rand Company
 Joy Manufacturing Company
 Nash Engineering Company
 Nooter Corporation
 Patterson-Kelly Company, Inc.
 Penberthy Manufacturing Company
 Roots-Connersville Blower
 Schutte and Koerting Company
 Struthers Wells Corporation
 Union Carbide Corporation
 Whitlock Manufacturing Company
 Westinghouse Electric Corporation
 Worthington Corporation

Cost estimation for the equipment made of special materials involved a substantial amount of additional work on the part of the manufacturers. The problem of obtaining this information was complicated by the fact that most of the prospective manufacturers had a heavy backlog of orders and were not strongly inclined to investigate new equipment with specialized materials. However, a few manufacturers responded favorably to the inquiries and provided sufficient information for the study. The price information obtained varied so widely from one manufacturer to another that extreme care had to be exercised to select cost data for the study. Evidently, the manufacturers did not have enough fabricating experience with the use of the specified materials to be able to predict prices accurately.

In addition to the great price variations, many discrepancies were found in the size and the design of equipment offered for identical service by different manufacturers. The technique of designing ejectors, barometric condensers, and surface condensers handling a mixture of steam and noncondensable gases is neither exact nor standardized. Most of the design rules are of a proprietary nature based upon experience of the manufacturer. These circumstances required independent design studies to be made to confirm proper sizing of the equipment, and the prices were adjusted accordingly. The costs selected for the detailed comparison of various types of equipment are presented in Figures 5 through 9.

Although designing the atmospheric decarbonator is outside the scope of this report, a representative design was developed in order to evaluate its usefulness in reducing the cost of the vacuum equipment. A five-step cascade or water-fall type decarbonation basin made of concrete was selected for this service. The cost of such a basin to handle the feed flow for a 50-Mgd plant is estimated to be \$150,000,

Figure 5
CAPACITY VERSUS EJECTOR COST
(Hastelloy Construction)

Figure 6

CAPACITY VERSUS BLOWER COST
 (Mixture of noncondensables and water vapor.
 Blower made of cast iron with 3% nickel)

Figure 7
BAROMETRIC CONDENSER COSTS
(Type 316 SS)

NOTE: MULTI-PASS CONDENSERS WITH FIXED HEADS AND FLEXIBLE TUBE SHEETS - HASTELLOY-C CONSTRUCTION EXCEPT HEADS ARE STEEL LINED WITH HERESITE.

Figure 8
SURFACE CONDENSER COSTS

Figure 9
SURFACE PRECONDENSER COSTS

including the incremental cost of feed pumps for the additional head requirement.

9.0 SYSTEMS STUDY

9.1 Bases

- 9.1.1 Steam. OSW ground rules for 50-Mgd plants established the cost of steam as 31.8¢/MBtu at 100 psig and 100°F superheat. This is equivalent to 33.9¢/1000 lb at 100 psig, saturated, when the condensate is returned at 90°F.

The plant load factor is 90%.

- 9.1.2 Cooling Water. The cost of cooling water capacity was fixed at \$1.75/gpm/yr derived as follows:

Capital investment (piping and pumps)	\$7.27/gpm
Annual Cost	
Fixed charges, 5.78%	0.42
Maintenance, 1% of capital investment	0.07
Power at 6.2 mills/kw-hr, 120-ft head	1.26
Total Annual Cost	\$1.75/gpm

The inlet seawater temperature was fixed at 65°F.

- 9.1.3 Value of Product Water. The condensate collected in the surface condensers was credited at \$0.36/1000 gallons.

- 9.1.4 Fixed Charges. The fixed charge assumed throughout the study was 5.78%.

- 9.1.5 Electrical Power. The power cost established by the OSW was 6.2 mills/kw-hr and was used throughout the study.

9.2 Economic Evaluation

Blowers and surface condensers involve relatively high capital costs and low operating costs, while the ejectors and the barometric condensers require lower capital costs and higher operating costs; therefore, the interest and amortization rates can greatly influence the preferential choice of equipment.

Two-stage ejectors are generally used for pressures in the range of 0.5 to 4.0 inches of mercury (Abs), while three-stage ejectors are used to reach pressures from 0.02 to 2.0 inches Hg Abs. Two-stage ejector systems cost about 20% less than three-stage ejectors, but are less efficient and use about 25% more steam. An ejector

system employing barometric condensers costs about half of one using surface condensers; but, with barometric condensers using seawater as the cooling medium, no possibility exists for recovery of water vapor or motive steam as product.

In general, high steam costs favor the use of three-stage ejector systems, while low steam costs coupled with short equipment amortization periods favor the two-stage units. Similarly, two-stage blower systems will have lower capital cost than three-stage blower systems, but the higher temperature rise will reduce the efficiency of the blowers somewhat.

9.2.1 Ejectors. Ordinarily, an ejector system design is obtained by submitting an outline of the performance requirements to ejector manufacturers. The vendors propose the best (in their judgment) system, giving the number of stages, pressures at each point, steam requirements, inter-condenser sizes, cooling water requirements, and finally the price. Various proposals are then compared and the best design selected.

The economic factors involved in the present study are complex; therefore, the vendors could not be expected to visualize all factors involved and offer the optimum designs. We developed our own methods of calculations and calculated performance of each ejector and condenser independently. The steam requirements for the ejectors were determined from manufacturer's data and verified by comparison with published data.⁽³⁾⁽⁴⁾

As an example of the design procedure, a given ejector system load was selected. The following system variables were fixed:

1. Type of condenser (surface or barometric).
2. Motive steam conditions 100 psig, saturated.
3. Condenser cooling water inlet temperature 65°F.
4. Condenser cooling water outlet temperature (maximum of 110°F and terminal temperature difference of not less than 8°F).
5. Gas outlet temperature.
6. Load composition and conditions (Case I or Case II, saturated with water vapor at 88°F).
7. Intermediate pressures - The ejector and blower systems were designed so that compression-to-atmospheric pressure was accomplished with equal increments of stage

compression ratios. Tables VI and VII show the pressure tapers in two-stage and three-stage ejector systems. The differences indicated for barometric and surface condensers are the result of different pressure drops inherent in the two types of equipment.

These conditions completely defined a performance requirement which was met as indicated above. Heat and material balances established the temperature and cooling water requirements.

With the use of the design procedure described above, computations were made to select the optimum number of stages for the ejector systems. It can be seen from Figure 10 that saving of steam in going from three to four stages is negligible; therefore, additional equipment cost precludes utilization of four-stage systems. The steam requirement differences between two and three stages are substantial; therefore, detailed calculations had to be made to select the most economical arrangement. Table VIII gives a summary of the cost analysis made on the various two- and three-stage ejector systems. The ejector costs shown include the cost of associated piping.

9.2.2 Blowers. A similar cost and performance problem exists with blowers as with ejectors. It would be not expected that the blower manufacturers could participate in a complete systems study without some type of compensation. However, sufficient cost information was obtained to justify confidence in estimates of blower cost as a function of suction volume and compression ratio.

The design procedure for blower systems was essentially the same as for ejectors. Tables VI and VII shows the pressure gradients in two-stage* and three-stage blower systems. The extremely high temperature rise and poor efficiency precluded the use of a single-stage blower system. Four-stage centrifugal blowers would result in exorbitant capital costs, which would never be compensated by slightly better operating efficiency.

Table IX gives a summary of the cost analysis made on the various blower systems considered for this study. The blower cost shown includes the cost of speed-changing gears, motors, and associated electrical hardware.

* Here, the word "stage" signifies the steps into which the overall compression is divided into to provide intercooling and not the number of impellers in a centrifugal blower.

TABLE VI
PRESSURES IN A TWO-STAGE BLOWER OR EJECTOR SYSTEM

	Pressure, psia Suction		Pressure, psia Discharge	
	Barometric	Surface	Barometric	Surface
Stage 1	0.86	0.82	3.65	3.65
Stage 2	3.47	3.28	14.7	14.7

TABLE VII
PRESSURES IN A THREE-STAGE BLOWER OR EJECTOR SYSTEM

	Pressure, psia Suction		Pressure, psia Discharge	
	<u>Barometric</u>	<u>Surface</u>	<u>Barometric</u>	<u>Surface</u>
Stage 1	0.86	0.82	2.29	2.29
Stage 2	2.18	2.06	5.81	5.81
Stage 3	5.52	5.23	14.7	14.7

Figure 10
EJECTOR STATION STEAM CONSUMPTION
VERSUS NUMBER OF STAGES

TABLE VIII

EJECTOR SYSTEMS COST SUMMARY

(Costs based on OSW ground rules for 50-Mgd plants)

Case	No. of Stages	Condenser Type	Cooling Water, gpm	Total Steam Consumption, lb/hr	Installed Cost			CO ₂ Release Pond	Total	Annual Costs						
					Ejectors	Condensers	Instrumentation and Controls			Fixed Changes	Maintenance	Steam	Cooling Water	Pond Pumping Power	Condensate Credit	Total
I	2	Surface	937	10,000	9,200	31,000	5,000	150,000	195,200	11,300	2,000	30,080	1,640	23,800	(2,630)	66,200
II	2	Surface	2,247	21,800	13,200	56,800	5,000	---	75,000	4,300	800	65,680	3,930	---	(6,020)	68,700
I	3	Surface	1,359	8,100	12,600	40,900	7,500	150,000	211,000	12,200	2,100	24,470	1,850	23,800	(2,840)	61,600
II	3	Surface	2,422	17,700	17,300	71,300	7,500	---	96,100	5,600	1,000	53,220	4,240	---	(6,480)	57,600
I	2	Barometric	498	9,000	9,200	11,000	5,000	150,000	175,200	10,100	1,800	27,000	893	23,800		63,600
II	2	Barometric	1,210	19,300	13,200	16,200	5,000	---	34,400	2,000	300	58,060	2,120	---		62,500
I	3	Barometric	515	6,900	12,600	13,800	7,500	150,000	183,900	10,600	1,800	20,740	900	23,800		57,800
II	3	Barometric	1,260	15,400	17,300	20,000	7,500	---	44,800	2,600	500	46,450	2,213	---		51,800

TABLE IX

BLOWER SYSTEMS COST SUMMARY

(Costs based on OSW ground rules for 50-Mgd plants)

Case	No. of Stages	Condenser Type	Total Cooling Water, gpm	Total Blower Power Consumption, hp	Installed Cost					Annual Operating Cost					Total Annual Cost
					Blowers	Condensers	Instrumentation	Pond	Total	Fixed Charges	Maintenance	Cooling Water	Electricity	Condensate Credit	
I	2	Surface	434	233	174,000	25,300	5,000	150,000	354,300	20,500	3,500	760	33,500	(800)	57,500
II	2	Surface	1,180	419	210,300	44,900	5,000	---	260,200	15,000	2,600	2,065	17,500	(2,100)	35,100
I	3	Surface	475	245	235,700	34,000	7,500	150,000	427,200	24,700	4,300	831	34,000	(900)	62,900
II	3	Surface	1,208	410	272,800	55,300	7,500	---	335,600	19,400	3,400	2,114	17,100	(2,200)	39,800
I	2	Barometric	300	219	168,700	9,700	5,000	150,000	333,400	19,300	3,300	500	32,900	---	56,000
II	2	Barometric	750	391	202,000	13,100	5,000	---	220,100	12,700	2,200	1,300	16,300	---	32,500
I	3	Barometric	300	230	228,400	13,800	7,500	150,000	399,700	23,100	4,000	500	33,400	---	61,000
II	3	Barometric	800	381	262,500	17,300	7,500	---	287,300	16,600	2,900	1,400	15,900	---	36,800

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9.3 Discussion of Systems Cost

9.3.1 Blowers. The optimum number of stages for blowers is two because the capital costs for more stages rise faster than savings in energy. One stage is not practical because of high temperature rise. Because of the high capital cost of small blowers (Figure 6), they are desirable mainly in large plants.

9.3.2 Ejectors. The optimum number of stages for an ejector system is three. Higher equipment costs make the four-stage system uneconomical, and high steam consumption makes the two-stage system uneconomical.

The ejector systems for 50-Mgd plants have higher costs than the comparable blower systems because of their high steam consumption. If more efficient steam jets could be made available or developed, their economics should be reviewed.

9.3.3 Barometric vs. Surface Condensers. For the most suitable design in each case, the barometric condensers are cheaper than surface condensers when all costs and savings are considered. The advantage favoring the surface condensers is recovery of condensate, while barometric condensers have the advantages of price, low pressure drop, less use of cooling water, and low maintenance cost. The difference in cost, in any event, is small compared to the overall system cost.

9.3.4 Decarbonating Pond. The cascade type degassing pond ($\Delta P = 12.5$ psi approximately) used in this study is uneconomical. It is cheaper to evacuate the carbon dioxide in vapor than to pump the liquid. However, a degassing pond with a lower pressure drop ($\Delta P = 2$ psi approximately) may prove to be economical if its initial cost is not very high.

There are other attendant benefits which result from the use of a pond; these are (1) reduction of tube surface area in deaerator and/or precooler and (2) reduction of corrosion in the condensers and in the plant. One disadvantage of the pond is that some designs require an extra pump to convey the feed water from the pond to the deaerator.

Optimization studies relating pond performance (in terms of degree of gas removal) versus cost were not considered to be a part of this study.

10.0 REVIEW OF 50-MGD CONCEPTUAL DESIGNS

An addition to the scope of this work has been the incorporation of a review of the noncondensable removal systems used by the conceptual designers of the 50-Mgd plants prepared for the OSW. Included in Table X is a brief review of each of these designs. The extent of information presented varied greatly from one designer to the other. Only those aspects of the design are included that are pertinent to the objectives of this report. If any aspect of these designs was either implied, stated in such a way as to have more than one interpretation, or was not clear, it was assumed as "not given" (abbreviated N.G.). This assumption was made in order to avoid any chance of misrepresenting the design.

A survey of all these different designs reveals that an important aspect of the noncondensable removal system design was the type materials used. The operating life of the equipment depends heavily upon the use of materials that can withstand the corrosive environment created by the presence of wet carbon dioxide, oxygen, and entrained moisture containing sodium chloride. The following is a list of the materials that are suggested for use in this service by the various designers:

Ejectors: Carbon steel, 316 and 316L SS, cast iron, Monel

Barometric Condensers: Neoprene or rubber-lined carbon steel

Surface Condensers:

Shell and Baffles: Carbon steel, 316 SS

Tubes: 90-10 Cu-Ni, Monel, 316 SS, aluminum, brass,
70-30 Cu-Ni

Tube Sheets: 90-10 Cu-Ni, Monel, 316 SS, 70-30 Cu-Ni,
aluminum bronze

Heads: Cast iron, lined steel, 90-10 Cu-Ni, bronze
steel

Investigations made in conjunction with this study indicate that stainless steels are subject to stress-corrosion cracking in the presence of chlorides. The alloys 90-10 Cu-Ni, 70-30 Cu-Ni, Monel, and aluminum brass are subject to pitting corrosion in this service. The corrosion rates of carbon steel and cast iron would be too high to be acceptable. While coatings seem to provide protection, the life expectancy at high temperatures are hard to predict.

Uncertainty also exists in other areas of design information. The amount of expected air inleakage varies from 75 lb/hr to 3500 lb/hr. The quantity of steam required for driving the ejectors varies from a low of 3,957 lb/hr to as high as 98,000 lb/hr for a 50-Mgd plant. Cooling water quantity also varies drastically from one design to the

TABLE X

SUMMARY OF 50-MGD NONCONDENSABLE REMOVAL SYSTEMS

	ALLIS- CHALMERS	APPLIED RESEARCH & ENGR. LTD.	AQUA-CHEM	THE BADGER CO.	BALDWIN- LIMA- HAMILTON	C. F. BRAUN	BURNS & ROE	DOW CHEMICAL	FLUOR CORP.	FOSTER- WHEELER	H. K. FERGUSON	GENERAL ELECTRIC	LOCKHEED	R. M. PARSONS	WORTHINGTON
Atmospheric Decarbonation Temp., F.	79	N. G.	72.5	Not Done	145	75	80.4	111	85	65	65	65	80.1	78.8	74
Decarbonation Temperature, F.	79	90	72.5		144	75	80.4	111	85	75	85	222	80.0	78.8	74
Decarbonation Pressure, psia.	0.49	0.7	.395		3.2	.43	0.51	1.31	.595	.43	.595	15	0.50	0.49	.415
<u>Evacuation Equipment for Deaerator:</u>															
No. of Stages	3	3	2	Deaeration is done at high pressure end of plant.	1	4	3	2	3	3	2	Not Needed	3	2	4
Type of Compressors	Ejectors	Ejectors	Ejectors		Piston	Rotary Lobe	Ejectors	Ejectors	Ejectors	Ejectors	Ejectors		Ejectors	Ejectors	Ejectors
Type of Precondenser	Surface	Surface	None		Surface	None	None	Barometric	Surface	Barometric	None		Surface	None	None
Type of Intercondensers	Surface	Surface	Surface		None	Surface	Surface	Barometric	Surface	Barometric	Surface		Surface	Barometric	Surface
Type of After Condensers	Surface	Surface	Surface		None	None	Surface	Barometric	Surface	Barometric	None		Surface	Barometric	Surface
<u>Evacuation Equipment for Evaporator:</u>															
No. of Systems Used	1	3	Uses	1	1	Uses	Uses	1	Uses	1	2	1	Uses	3	1
No. of Stages	1	2, & 3	Deaerator	2	1	Deaerator	Deaerator	2	Deaerator	3	1 & 2	2	Deaerator	2, & 2	3
Type of Compressors	Ejectors	Ejectors	System	Ejectors	Piston	System	System	Ejectors	System	Ejectors	Ejectors	Ejectors	System	Ejectors	Ejectors
Type of Precondenser	None	Surface		None	None			Barometric		Barometric	None	None		None	None
Type of Intercondensers	(1)	Surface		Barometric	None			Barometric		Barometric	Surface	(10)		Barometric	Barometric
Type of After Condensers	(1)	Surface		Barometric	None			Barometric		Barometric	Surface	(10)		Barometric	Barometric
<u>Deaerator Vent Quantities, lb/hr</u>															
Oxygen	237	770	N. G.	6900	100 cfm. (3)	480	1800	254	386 (4)	276 (4)		N. G.	2460	3700	1550 (4)
Nitrogen	378		N. G.			scfm.			805 (4)	552 (4)		N. G.			
Carbon Dioxide	1400	200	149			120 scfm.	290		830 (4)	690 (4)		N. G.	1440		
Water Vapor	8000	N. G.	N. G.	40,000	30,000	N. G.	12,500	295	(5)	12,450 (4)	2100	N. G.	39,000	N. G.	N. G.
<u>Evaporator Vent Quantities, lb/hr</u>															
Oxygen	N. G. (2)	N. G.	N. G.	970	15.6 scfm.	N. G.	Included	465	54	740		3500	Included	Included	504
Nitrogen	N. G.	N. G.	N. G.			N. G.	Above		179				Above	Above	
Carbon Dioxide	N. G.	N. G.	N. G.	N. G.		N. G.		0	0	0		N. G.			
Water Vapor	N. G.	N. G.	N. G.	600		N. G.		19,680	(6)	3200		11,600		N. G.	N. G.
Expected Air Inleakage, Total lb/hr	N. G.	N. G.	N. G.	970	75	1600	1000	465	690	740	N. G.	3500	N. G.	N. G.	504 (11)
Total Electric Power or Steam Used, Horsepower or lb/hr	1600	N. G.	8450	8100	133	N. G.	78,500 (7)	3957	15,400	19,765	12,800	16,600	33,200	98,000 (7)	18,720
Steam Temp. & Pressure, °F. & psia.	N. G. & 175	N. G.	466 & 165	N. G. & 165	-	N. G. & 115	N. G. & 115	314 & 82	338 & 115	438 & 115	438 & 115	N. G.	466 & 165	N. G.	438 & 115
Total Cooling Water Used, gpm.	5300	N. G.	480	1500	3800	1240	2490	1910	N. G.	7350	780	N. G.	5290	N. G.	4400
<u>Materials:</u>															
Ejectors:															
Nozzles	N. G.	N. G.	N. G.	SS	-	-	N. G.	Monel	316 SS	Steel & 316 SS	N. G.	SS	316L SS	N. G.	316SS & Monel (12)
Body	N. G.	N. G.	N. G.	Steel	-	-	N. G.	Steel	Steel	Steel & 316 SS (8)	N. G.	Steel	316L SS	N. G.	Steel
Compressors	-	-	-	-	-	Cast Iron	-	-	-	-	-	-	-	-	-
Piston-Type Vacuum Pumps	-	-	-	-	N. G.	-	-	-	-	-	-	-	-	-	-
Barometric Condensers:															
Body	-	-	-	Steel	-	-	-	Steel	-	Steel	-	Steel	-	N. G.	Steel
Lining	-	-	-	N. G.	-	-	-	N. G.	-	Rubber (9)	-	Rubber	-	N. G.	Neoprene
Surface Condensers:															
Heads	N. G.	N. G.	N. G.	-	Steel	Cast Iron	N. G.	-	Lined Steel	-	N. G.	Bronze	N. G.	-	Steel
Shell	N. G.	N. G.	N. G.	-	Steel	316 SS	N. G.	-	Steel & 316 SS	-	N. G.	Steel	316L SS	-	Steel
Tubes	N. G.	N. G.	N. G.	-	90-10 Cu-Ni	Monel	316 SS	-	70-30 Cu-Ni	-	N. G.	Al Brass	90-10 Cu-Ni	-	90-10 Cu-Ni
Tube Sheets	N. G.	N. G.	N. G.	-	90-10 Cu-Ni	Monel	N. G.	-	70-30 Cu-Ni	-	N. G.	Al Bronze	90-10 Cu-Ni	-	90-10 Cu-Ni

NOTES:

- (1) Feeds into deaerator evacuation system at the suction of first intercondenser.
- (2) N. G. stands for "not given."
- (3) Temperature and pressure not included.
- (4) Includes heat reject stages
- (5) Saturation amount.
- (6) 50 times by volume.

(7) Seems to be an error. It is too high.

(8) The deaerator ejectors are made of 316 SS and the evaporator ejectors are made of steel.

(9) Rubber lining is only for the first two condensers in the deaerator system.

(10) Conflicting information given. The report mentions surface condensers at one place and barometric condensers at another place.

(11) This is inleakage into recovery stages only. Inleakage into deaerator and reject stages is not given.

(12) 316 SS used for recovery stage ejectors. Monel used for deaerator ejectors.

other, indicating that there is a lack of standardized information on the characteristics of heat transfer when a mixture of noncondensables and steam is being cooled.

Another variance between designers is in the area of equipment selection. Although most of the designers have selected the steam-driven ejector as the basic evacuation unit, the arrangement of the system and its components do not seem to conform to any specific trend from one design to another. The number of stages used in the ejector systems varies from two to four; and while some used single full capacity ejectors, others used as many as four ejectors in parallel.

However, some useful and practical design concepts have been presented by some designers. These are as follows:

1. If deaeration is done at the high-pressure end of the evaporator, the large quantity of high pressure gases and associated water vapor leaving the deaerator can be used to drive the evacuation ejectors for the subatmospheric stages of the evaporator.
2. Multiple small units can be connected in parallel instead of single large units. Although this may increase the maintenance, it also increases the reliability of the system as the plant can be operated at part load if one of the units breaks down. The savings in initial investment are not clear cut. Whether the price of two small units is more or less than that of a single large unit depends largely upon the availability and use of any particular size of equipment.
3. Decarbonation and deaeration at elevated temperatures reduces the evacuation load.

A synopsis of each of the individual designs is given in Appendix B.

11.0 RECOMMENDED FUTURE WORK

OSW should subject coatings potentially suitable for this service to accelerated tests. The useful life of stainless steel, titanium, and Hastelloy C should be measured further in deaerator service.

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APPENDIX A

EFFECT OF LOW-COST ENERGY ON SYSTEM COSTS

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APPENDIX A

EFFECT OF LOW-COST ENERGY ON SYSTEM COSTS

Since cost of utilities (steam, electrical power) from large nuclear plants are expected to be much less than the OSW cost parameters used in the preceding study, we decided to determine also the effect of lower utility costs on the outcome of this study. The following cost parameters were used:

Steam: 10.9¢/1000 lb of dry saturated steam at 100 psig pressure. The temperature of condensate returning to the steam source is taken as 90°F.

Electric power: 2 mills/kw/hr

Annual fixed charges: 5.78% of capital investments. This includes interest and amortization.

On the basis of the above cost parameters, our economic evaluations indicate that two-stage blowers and three-stage ejectors give about equal costs and should be combined with barometric condensers.

Table XI and XII give a summary of total annual costs for all the systems considered.

TABLE XI

EJECTOR SYSTEMS COST SUMMARY

(Costs based on energy from large nuclear plants)

Case	No. of Stages	Condenser Type	Total Cooling Water, gpm	Total Steam Consumption, lb/hr	Installed Cost				Annual Cost							
					Ejectors	Condensers	Instrumentation and Controls	CO ₂ Release Pond	Total	Fixed Charges	Maintenance	Steam	Cooling Water	CO ₂ Pond Pumping Power	Condensate Credit	Total
I	2	Surface	937	10,000	9,200	31,000	5,000	150,000	195,200	11,300	2,000	10,290	843	7,700	(1,315)	30,900
II	2	Surface	2,247	21,800	13,200	56,800	5,000	---	75,100	4,300	800	32,450	2,023	---	(3,010)	26,600
I	3	Surface	1,059	8,100	12,600	40,900	7,500	150,000	211,000	12,200	2,100	8,355	953	7,700	(1,420)	29,900
II	3	Surface	2,422	17,700	17,330	71,300	7,500	---	96,100	5,600	1,000	18,200	2,180	---	(3,250)	23,800
I	2	Barometric	498	9,000	9,200	11,000	5,000	150,000	175,200	10,100	1,800	9,225	450	7,700	---	29,300
II	2	Barometric	1,210	19,300	13,200	16,200	5,000	---	34,400	2,000	300	19,880	1,080	---	---	23,260
I	3	Barometric	515	6,900	12,500	13,800	7,500	150,000	183,900	10,600	1,800	7,070	460	7,700	---	27,600
II	3	Barometric	1,260	15,400	17,300	20,000	7,500	---	44,800	2,600	500	15,825	1,130	---	---	20,100

TABLE XII
BLOWER SYSTEMS COST SUMMARY
(Costs based on energy from large nuclear plants)

Case	No. of Stages	Condenser Type	Total Cooling Water, gpm	Total Blower Power Consumption, hp	Installed Cost					Annual Operating Cost					
					Blowers	Condensers	Instrumentation	Pond	Total	Fixed Charges	Maintenance	Cooling Water	Electricity	Condensate Credit	Total
I	2	Surface	434	233	174,000	25,300	5,000	150,000	354,300	20,500	3,500	390	10,800	(400)	34,400
II	2	Surface	1,180	419	210,300	44,900	5,000	---	260,200	15,000	2,600	1,060	5,600	(1,050)	22,200
I	3	Surface	475	245	235,700	34,000	7,500	150,000	427,200	24,700	4,300	428	11,000	(450)	39,500
II	3	Surface	1,208	410	272,800	55,300	7,500	---	335,600	19,400	3,400	1,087	5,500	(1,100)	27,200
I	2	Barometric	300	219	168,700	9,700	5,000	150,000	333,400	19,300	3,300	200	10,700	---	33,500
II	2	Barometric	750	391	202,000	13,100	5,000	---	220,100	12,700	2,200	700	5,300	---	20,900
I	3	Barometric	300	230	228,400	13,800	7,500	150,000	399,700	23,100	4,000	300	10,800	---	38,200
II	3	Barometric	800	381	262,500	17,300	7,500	---	287,300	15,600	2,900	700	5,100	---	25,300

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APPENDIX B

DEAERATION SYSTEMS OF THE OSW 50-MGD DESIGNS

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APPENDIX B

DEAERATION SYSTEMS OF THE OSW 50-MGD DESIGNS

Allis-Chalmers

Atmospheric decarbonation is done at 79°F where the seawater flows into the deaerator. High pressure stages are vented directly to atmosphere without an external condenser. The evaporator stage noncondensables are cascaded from stage to stage down to the last stage. The plant uses a three-stage steam ejector system with inter-condensers and an after-condenser. There are two first-stage ejectors, one for the deaerator and the other for the evaporator. Only the deaerator ejector is preceded by precondensers. All condensers are surface type, use seawater, and are connected in parallel. The evaporator stages have a baffled cooling section for the noncondensable mixture leaving the tube bundle.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Evaporator high-pressure stages	-----	N.G.	-----	-----
Evaporator low-pressure stages	-----	N.G.	-----	-----
Deaerator	237	378	1400	8000

Expected Air Inleakage: N.G.

Total Ejector Steam: 16,000 lb/hr at 175 psia (temperature N.G.)

Total Cooling Water: 5300 gpm

Materials: N.G.

Aqua-Chem

Decarbonation and deaeration are both done at 72.5°F. The heat recovery evaporator vent gases are cascaded from stage to stage down to the lowest* pressure stage and then to the evacuation system. The vent gases in the reject stages are also cascaded down to the last stage, which is also the deaerator, and then to the evacuation system. It is not clear whether the heat recovery evaporator vent gases and the deaerator vent gases are fed into the vacuum system at the same pressure or different pressure levels, as two conflicting flow diagrams are presented. A gas cooling section is provided in each evaporator stage tube bundle. The

* The write-up, as well as the flow diagram, indicates that the vents are being cascaded upward toward higher pressures and are removed from the highest pressure stage. This is not possible; therefore, we assume it to be an inadvertent error in the report.

vacuum system is a two-stage steam ejector system with inter- and after-condensers. The condensers, connected in series, use seawater which is fed to the evaporator.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Vacuum deaerator	N.G.	N.G.	149	N.G.
Evaporator	-----N.G.-----			

Expected Air Inleakage: N.G.

Total Ejector System: 8450 lb/hr at 150 psig and 466°F

Total Cooling Water: 480 gpm

Materials: N.G.

Applied Research and Engineering, Ltd.

An atmospheric forced draft and packed degassing tower and a vacuum deaerator are used for removal of noncondensable gases. The operating temperature of the deaerator is 90°F and the temperature of atmospheric degassing is not given. Several sets of steam-driven ejectors with different number of stages are used. All systems use surface type pre-, inter-, and after-condensers which are connected in series on the cooling water side. The cooling water is taken directly from the incoming seawater. The deaerator is equipped with a separate three-stage ejector system. The evaporator stages are divided into three groups, and the vent gases are cascaded down to the lowest pressure in each group. The highest pressure group uses a single-stage ejector; the intermediate pressure group uses a two-stage ejector system; and the lowest pressure group uses a three-stage ejector system. Details of vent gas take-offs are not given.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Vacuum deaerator	-770 total--		200	N.G.
Evaporator	-----N.G.-----			

Expected Air Inleakage: N.G.

Total Ejector Steam Used: N.G.

Total Cooling Water: N.G.

Materials: N.G.

The Badger Company

The plant is tubed with titanium tubes; therefore, atmospheric decarbonation is not done, and the deaeration is done in the evaporator at the high-pressure end of the plant. A two-stage ejector system with barometric inter- and after-condensers is used to evacuate the subatmospheric stages of the evaporator. No precondenser is used. The evaporator stages are divided into several groups. In each group, the vent gases are cascaded down to the lowest pressure stage, passed through a cooling section, and then vented to the corresponding pressure point in the ejector system. The vent gases leaving the high-pressure stage drive the second stage ejector. Steam from the power station is used for the first ejector and as a standby for the second ejector. Product water is used in the barometric condensers. The noncondensables are removed from the lower interior section of each tube bundle by a perforated header that runs parallel to the tubes. Removal rate of the noncondensables is maintained by a slide valve which can be adjusted only during shutdown of the plant.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Evaporator high-pressure stage	---6900	O ₂ +N ₂ +CO ₂ ---		40,000
Evaporator low-pressure stage	----	970 Air--	N.G.	600

Expected Air Inleakage: 970 lb/hr

Total Ejector Steam: 8100 lb/hr at 165 psia (temperature N.G.)

Total Cooling Water: 1500 gpm

Materials: Barometric condensers, lined carbon steel (lining N.G.)
Ejectors, carbon steel with stainless steel (type N.G.)
nozzles

Baldwin-Lima-Hamilton

Since atmospheric decarbonation is done at 145°F; load on the deaerator is considerably reduced. Separate piston-type, single-stage vacuum pump systems are used for the evaporator and the deaerator. The deaerator pump is equipped with a surface-type precondenser. The evaporator stage vent gases are all manifolded together; details of vent gas take-offs are obscure. No after-condensers are used and seawater is used in the condenser.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Evaporator	-----	15.6	scfm total---	
Deaerator	-----	100	cfm* total-	30,000

* Temperature and pressure N.G.

Air inleakage: 15.6 scfm

Total power consumption: 133 hp

Cooling water quantity: 3800 gpm

Materials: Vacuum pumps, N.G.

Surface condenser: Carbon steel with 90-10 Cu-Ni tubes
and tube sheets

C. F. Braun & Co.

Decarbonation and deaeration is done at 75°F. Noncondensables are cascaded from stage to stage and effect to effect to the deaerator, and then removed by a system of four-stage rotary-lobe compressors. The intercoolers (surface type) use seawater and are connected in parallel. No precooler is used in this design. Details of vent gas take-offs are not presented.

Vent Gas Quantities:	$\frac{O_2}{2}$	$\frac{N_2}{2}$	$\frac{CO_2}{2}$	$\frac{H_2O}{2}$
Leaving deaerator	-480 scfm total-	120 scfm	N.G.	

Expected air inleakage: 370 scfm

Total power consumption: N.G.

Cooling water quantity: 1240 gpm

Materials:

Coolers: Monel tube and tube sheets
316 SS baffles and shell
Cast iron or steel channel

Compressors: Cast iron lobes and casing
SAE 4140 shaft

Burns and Roe

Decarbonation and deaeration is done at 80.4°F. A three-stage ejector system is equipped with inter- and after-surface condensers, but no precondenser is used. Noncondensables from all the heat recovery stages are manifolded together, as are the noncondensables from the heat reject stages. The first ejector evacuates the deaerator and the heat reject stages. Gases from the heat recovery stages are introduced into the suction of the second ejector. Vent gas take-off from the deaerator is through a perforated header below the trays; from the evaporator stages, vent gases are collected from the lower part of the tube bundle at the colder end.

Vent Gas Quantities, lb/hr:	<u>Air</u>	<u>CO₂</u>	<u>H₂O</u>
Evaporator and deaerator	1800	290	12,500

Expected air inleakage: 1000 lb/hr max. (includes allowance for temporary high leakage rates)

Total ejector steam: 78,500 lb/hr at 100 psig (temperature N.G.)

Total cooling water: 2,490 gpm seawater. Condenser connected in parallel

Materials: Ejectors, N.G.
Condensers, 316 SS tubes. Other materials N.G.

The Dow Chemical Company

Decarbonation and deaeration in this design are done at 110°F. The deaerator and the evaporator have two separate two-stage ejector systems with pre-, inter-, and after-condensers (barometric). Precondensers use seawater and others use product water. High-pressure-stage vent gas drives the first ejector of the deaerator and other ejectors are driven with steam from the power station. Details of vent take-offs are not clear. It is not readily apparent, but it was assumed that the noncondensables are cascaded from stage to stage down to the last stage. Details of vent take-offs are obscure.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
From deaerator	-----	254 total-----		295
From evaporator HP stage	-----	506 total-----		
From evaporator LP stage	---	465 total---	0	19,680

Expected air inleakage: 465 lb/hr

Total ejector steam required: 3,957 lb/hr at 82 psia saturated

Total cooling water: 1760 gpm of seawater, 149 gpm of product water
Cooling water connect in parallel

Materials: Ejectors, cast steel with monel nozzles
Condensers, steel

The Fluor Corporation

In this design, decarbonation and deaeration are done at 85°F. It incorporates a three-stage ejector with surface type pre-, inter-, and after-condensers; there are three identical systems connected in parallel. Seawater is used in condensers connected in parallel. The evaporator heat recovery stages are divided into several groups. Vent gases in each group are manifolded together and introduced into the corresponding pressure points of the ejector system. The heat reject

stages and the deaerator are vented to the precondenser. Vent gas take-offs are from the center of the bundle where an open space is provided for the noncondensables to collect. Gases leave the bundle through a baffled area that does not have tubes for further cooling.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
From deaerator and heat reject stages	386	805	830	Saturation amount
From heat recovery stages	54	179	0	50 times by volume

Expected air inleakage: 690 lb/hr

Steam consumption: 15,400 lb/hr at 100 psig saturated

Cooling water quantity: N.G.

Materials: Ejectors, 316 SS except steam chest in carbon steel
 Inter-condensers, 70-30 Cu-Ni tubes and tube sheets, carbon steel
 Shell, 90-10 Cu-Ni or phenolic-lined steel water boxes
 After-condenser, Duplex 90-10 Cu-Ni and 316 SS tubes, 70-30 Cu-Ni tube sheets, 316 SS shell, 90-10 Cu-Ni or phenolic-lined steel water boxes

Foster Wheeler Corporation

This design provides for decarbonation at 65°F and deaeration at 75°F. Two separate systems are used for removing noncondensables. One system evacuates the deaerator and the heat reject stages; it consists of three-stage ejectors with pre-, inter-, and after-barometric condensers. The other system evacuates the heat recovery stages of the evaporator; it consists of three-stage ejectors with inter- and after-barometric condensers. The heat recovery stages are divided into several groups; the stages in each group are cascaded down to the lowest pressure stage from where the gases are introduced to the corresponding pressure point of the evacuation system. The pre-condenser and the first inter-condenser of the deaerator evacuation system use seawater for cooling and all the other condensers use product water. All cooling water systems are connected in parallel. Gases are removed from the center of each bundle and pass through a baffled cooling section of the bundle.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Leaving deaerator	276	552	690	12,450
Leaving evaporator	--740 total air-		0	3,200

Expected air inleakage: 740 lb/hr

Total ejector steam: 19,760 lb/hr at 100 psig, 100°F superheat

Total cooling water: 5,670 gpm seawater; 1,680 gpm product water

Materials: Deaerator ejectors, 316 SS with carbon steel steam chest
 Evaporator ejectors, carbon steel
 Barometric condensers, carbon steel. The first two of the deaerator system are lined with rubber.

The H. K. Ferguson Company

Decarbonation in this design is done at 65°F and deaeration at 85°F. Three different systems of ejectors and surface condensers are used for the plant. The deaerator is evacuated by a two-stage ejector system with an inter-condenser; no pre- or after-condenser used. The evaporator stages are divided into three groups. The high-pressure stages are vented directly to atmosphere through a condenser. The intermediate stages are vented through a single-stage ejector with an after-condenser only. The lower pressure stages are vented through a two-stage ejector system with inter- and after-condensers. All condensers use seawater for cooling.

The evaporator stages in each group are manifolded together. Details of vent gas take-offs from the evaporator stages are not shown.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Deaerator	-----2100 total-----			
Evaporator	-----134 total-----			

Expected inleakage of air: N.G.

Total ejector steam: 12,800 lb/hr at 100 psig and 100° S.H.

Total cooling water used: 780 gpm

Materials: N.G.

General Electric

This design provides for decarbonation at 65°F in an open pond; deaeration is done at 222°F at slightly above atmospheric pressure and the deaerator is vented directly to atmosphere. Vent gases from the low-pressure effects are all manifolded together and evacuated by a two-stage steam ejector system using barometric condensers. The condensers are connected in series and use seawater which is discharged back to sea. Gases are collected from each tube bundle, where baffled zones are provided for collection of noncondensables.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Low-pressure effects of evaporator	--3500 air---	N.G.	11,600	

Expected air inleakage: 3,500 lb/hr

Total ejector steam: 16,600 lb/hr (conditions N.G.)

Total cooling water: N.G.

Materials: Ejectors, Steel with stainless steel (type N.G.)
 steam nozzle
 Condensers, Rubber-lined shell; bronze water boxes;
 aluminum brass tubes; aluminum bronze
 tube sheets.

Lockheed Missile and Space Company

Decarbonation and deaeration in this design are both done at 80.1°F. Vent gases from each stage and the deaerator are manifolded together and evacuated by a system of three-stage ejectors with pre-, inter-, and after-condensers (surface type). The condensers use seawater for cooling and are connected in parallel. The noncondensables are picked up from the center of the bundle by a perforated pipe that runs the length of the bundle. No baffled vent gas cooling zone is provided.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Deaerator and evaporator	--2460 total--		1440	29,000

Expected air inleakage: N.G.

Total ejector steam: 33,200 lb/hr at 150 psig and 100°F S.H.

Total cooling water: 5,290 gpm

Materials: Condensers, tubes and tube sheets are 90-10 Cu-Ni;
 shell is 316L SS; head material N.G.
 Ejectors, 316L SS

R. M. Parsons Company

Decarbonation is done at 78.5°F from where the water directly goes to the vacuum deaerator. The deaerator is evacuated by a two-stage steam ejector system. The low-pressure stages of the evaporator are divided into three groups and each group is evacuated by a two-stage steam driven ejector system. All four of the two-stage ejector systems do not have precondensers, but barometric inter-condensers are used and they vent through a single common barometric after-condensers. All condensers use product water for cooling. In each group of the evaporator stages, the noncondensables are cascaded from stage to stage down to the lowest pressure stage. Noncondensables in each stage are removed from the lower middle of the tube bundle by a perforated collection pipe, which runs lengthwise with the tube bundles.

Vent Gas Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
Vacuum deaerator	-----	3700 total	-----	N.G.
Evaporator	-----	included above	---	N.G.

Expected air inleakage: N.G.

Total ejector steam: 98,000 lb/hr, conditions N.G.

Total cooling water: N.G.

Materials: N.G.

Worthington Corporation

This design provides for atmospheric decarbonation at 74°F, from where the seawater flows directly into the deaerator. Two evacuation systems are used. A four-stage ejector system with surface type inter- and after-condensers is used for the subatmospheric stages of the heat recovery section, and a three-stage ejector system with barometric inter- and after-condensers is used for the heat reject stages and for the deaerators. The high-pressure stages are vented directly to atmosphere without an outside cooler. The vent gases from the subatmospheric stages of the heat recovery section are manifolded together into several groups, and each is introduced into the evacuation system at a corresponding pressure. The barometric condensers use seawater flowing in parallel, and the water is rejected to the sea. The surface condensers use blowdown brine connected in series, and this brine is returned to the heat reject section. In each stage the noncondensables are collected from the middle of the bundle. The gases are drawn out through a baffled section of the bundle which acts as a cooler.

Vent Quantities, lb/hr:	<u>O₂</u>	<u>N₂</u>	<u>CO₂</u>	<u>H₂O</u>
High-pressure recovery stages	-----	N.G.	-----	-----
Low-pressure recovery stages	--504 total		0	N.G.
Deaerators and heat reject stages	-----	1552 total	-----	N.G.

Expected air inleakage: 504 lb/hr into recovery stages
Inleakage into reject stages and deaerator N.G.

Total ejector steam: 18,720 lb/hr at 100 psig, 100°F S.H.

Cooling water for barometric condensers: 2000 gpm

Cooling water for surface condensers: 2400 gpm

Materials: Recovery section ejectors, Carbon steel, cast iron, 316 SS
Surface condensers, Carbon steel and 90-10 Cu-Ni
Deaerator and heat rejection ejectors, Carbon steel and monel
Barometric condensers, Neoprene-lined carbon steel

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BASIS FOR CALCULATION OF GAS LOADS

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APPENDIX C

BASIS FOR CALCULATION OF GAS LOADS

The amount of air and carbon dioxide that will enter the system with the seawater can be determined from existing data on dissolved gases in seawater and from the stoichiometry of the reaction between sulfuric acid and carbonates. This inleakage is largely a function of the structural design, the materials of construction, and the quality of workmanship employed in assembling the shell; we estimated the rate of air inleakage at 200 lb/day. This figure reflects a combination of our experience and that of others¹⁻³ with large vacuum systems. We also considered the experience of the utility industry with steam surface condensers operating under vacuum in large power plants.

The most suitable method for correlating this information is to base the inleakage flows on the total volume and/or the total length of joints involved in the vacuum system. Carolinas-Virginia Nuclear Power Associates^{2,3} conducted very extensive leak rate tests on their reactor containment vessel, which is similar to an evaporator plant in construction. For vessel pressures of 22.5 and 13.1 psig, their leakages to atmosphere amounted to 0.074 and 0.054%/day, respectively, of the contained volume. When converted to the pressure conditions of a typical evaporator plant, these leakage rates amount to 0.029%/day of the contained volume.

Compared with these data, the estimate of 200 lb/day of air inleakage appears reasonable for design purposes. This amount represents an approximate rate of 1.17 lb/day per 100 ft of seal weld, 0.333 lb/day per 1000 ft³ of vacuum space, or 0.455%/day of contained volume. We feel that large subatmospheric plants can be built to operate with such inleakage rates provided proper vacuum construction techniques and good workmanship are employed, including checking for leaks over the entire length of each joint.

¹"Research on and Analysis of Single-Effect Low Temperature Flash Evaporation Process," Office of Saline Water, Research and Development Progress Report No. 18, pp. 30-32, 1958 (reprint of Griscom-Russell Company report).

²"CVTR Vapor Container Leak Rate Tests," Carolinas-Virginia Nuclear Power Associates, Report CVNA-106, April, 1962.

³"Vapor Container Leak Rate Test," Report CVNA-208, Carolinas-Virginia Nuclear Power Associates, April, 1964.

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