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PERFORMANCE ASSESSMENT OF FLASHED STEAM GEOTHERMAL POWER PLANT

RP1195-1

Theodore E. Alt, PE
Arizona Public Service Company
P. O. Box 21666
Phoenix, Arizona, 85036, (602) 271-7900

Introduction Five years of operating experience at the Comisión Federal de Electricidad Cerro Prieto flashed steam geothermal power plant are evaluated from the perspective of U. S. utility operations. We focus on the design and maintenance of the power plant that led to the achievement of high plant capacity factors for Units No. 1 and 2 since commercial operation began in 1973. For this study, plant capacity factor is the ratio of the average load on the machines or equipment for the period of time considered to the capacity rating of the machines or equipment.

The plant capacity factor is the annual gross output in GWh compared to 657 GWh (2 x 37.5 MW x 8760 h). The following table shows the annual output and PCF for the years 1974-1978.

YEAR	GWH	FACTOR
1974	463	0.70
1975	518	0.79
1976	579	0.88
1977	592	0.90
1978	598	0.91

The CFE operates Cerro Prieto at base load consistent with the system connected electrical demand of the Baja California Division. The plant output was curtailed during the winter months of 1973-1975 when the system electric demand was less than the combined output capability of Cerro Prieto and the fossil fuel plant near Tijuana. Each year the system electric demand has increased and the Cerro Prieto units now operate at full load all the time.

The CFE added Units 3 and 4 to Cerro Prieto in 1979 which increased the plant name plate capacity to 150 MW. Part of this additional capacity will supply power to San Diego Gas and Electric Company through an interconnection across the border.

The achievement of a high capacity factor over an extensive operating period was influenced by operation, design, and maintenance of the geothermal flash steam power plant.

Geothermal Power Plant Operation The operation of a geothermal steam electric plant is relatively simple compared to a fossil fuel steam electric plant. A flow diagram for the steam cycle of a geothermal plant is shown in Figure No. 1. The equipment for either plant is similar, e.g., steam piping, turbo-generator, circulating water system, cooling tower, air-ejectors, and condenser. The operation of this equipment is known to many electric utility plant personnel, but the fossil fuel steam plant problems involving fuel handling, ash handling, combustion, and feedwater systems are absent in the geothermal facility. Multiple wells supplying steam to the geothermal plant are an advantage compared to a single boiler steam supply in the fossil fuel plant in many respects.

The flash steam geothermal plant and the hydro-electric plant appear similar in their manner of operation. Both types of plant conduct the working fluid through the prime mover turbine; both obtain an energy supply from a large reservoir; both base load the generating units consistent with system electrical demand and reservoir ability to supply input energy. The operation of the geothermal plant can be compared to the hydro-electric plant for manning requirements and plant capacity factor goals.

Geothermal Power Plant Design Figure No. 2 shows the basic design for the Cerro Prieto geothermal units. Most of the equipment arrangement is familiar to steam electric power plant personnel.

The direct contact barometric condenser is unique for geothermal steam plants. Usually, the condenser is a closed surface type heat exchanger that returns condensate to the boiler plant. Cooling water does not have direct contact with the steam exhaust from the turbine.

In the direct contact barometric condenser, the turbine exhaust steam is condensed by direct mixture with the cooling water flow. Direct contact of the cooling water and exhaust steam gives optimum condenser heat transfer. The combined liquid flows to the cooling tower for heat rejection; a portion of the flow is discharged to evaporation ponds to maintain the desired water quality in the cooling tower basin.

Three steam jet air ejectors are installed in each unit to remove non-condensable gases from the condenser. Usually only two air ejectors are required to handle the non-condensable gas flow. The spare ejector has been helpful when it was necessary to remove an ejector from service for maintenance while the generating unit continued in service.

Materials of Construction, Design One thousand tests were conducted on a number of candidate materials prior to the selection of materials for the critical parts of the plant. Samples were exposed to the geothermal steam, both aerated and non-aerated and to condensate, for a period of 150 days. The steam was obtained from Cerro Prieto well M-8 and the condensate from steam from wells M-3 and M-5.

The material for equipment fabrication was selected on recommendations of the manufacturers plus CFE candidate material tests. Operating experience has confirmed that most of the material selection was correct.

There have been some corrosion problems with the metal alloys supplied by the manufacturers. Before discussing the material modifications that required outages or impaired the achievement of high capacity factor, we will describe some of the power plant equipment.

Power Plant Equipment, Turbine Generator The turbine generators were supplied by the Toyko Shibaura Electric Company, Ltd. (Toshiba). The steam turbines are of the single-cylinder, double-flow type with six stages of impulse-reaction blades in each flow path. The generator is rated at 44,200 kVA, 13.8 kV, 60 hz, and a power factor of 0.85. The speed of rotation is 3600 RPM, and both the rotor and the stator are hydrogen cooled.

The turbine rotor is machined from a 1 Cr-1 Mo-1/4 V alloy steel forging, and forms a shaft, wheels, bearing journals and coupling flanges. Alloy steels containing Ni are not used because of their poor corrosion resistance. The turbine blades are machined from 12 Cr alloy steel bar stock; they are enclosed with a shroud which is hand-riveted in place. The blades of the last row are fitted with stellite erosion shields and fastened together with lashing wire to minimize vibrations. The nozzle partitions are of 12 Cr-0.2 Al alloy steel, and the labyrinth strips are of 15 Cr-1.7 Mo alloy steel. The turbine outer and inner casing are made of carbon steel according to ASTM specification ASTM-A285.

Power Plant Equipment, Barmometric Condenser The condenser is a direct-contact barometric type located adjacent to the power house as shown in Figure No. 2. The exhaust from the turbine is conveyed to the condenser by means of a duct which is 3.6 m (11.8 ft) in diameter and about 40 M (131 ft) in length, including three right-angle bends. Non-condensable gases are removed from the top of the condenser shell through a 0.7 m (2.3 ft) diameter pipe.

The shell of the condenser is carbon steel with an interior protective coating of epoxy resin. Circulating water is distributed across the exhaust vapor inlet by means of nozzles and trays made of Stainless Steel AISI 304L. The condenser is 25.35 m (83.2 ft) high with a shell diameter of 6.7 m (22 ft), shell height of 9.6 M (31.5 ft), and tail pipe 2 m (6.6. ft) in diameter and 12 m (39.4 ft) in length. Condensers are shown in Figure No. 3.

Power Plant Equipment, Non-Condensable Gas Extraction The gas extraction system consists of a two-stage steam ejector with an inter- and after-condenser. There are three first-stage steam ejector nozzles that operate in parallel, each is connected to a separate inter-condenser. There are three second-state steam ejectors, also in parallel, and three-after-condensers. The gas extraction system receives motive steam from the main steam line and cooling water from the circulating water system.

The non-condensable gases removed from the condenser by means of the steam ejector system are discharged to the atmosphere through 475 mm (18 in) diameter fiberglass pipes (one for each unit) which extend to a height of 40 m (131 ft) above the ground. The prevailing winds blow these gases away from the plant. On windless days, the concentration of H_2S may reach dangerous levels in certain areas. An additional vent line was constructed from the power house at the base of the gas extraction stacks to the evaporation pond. The resin-lined, steel vent duct is 584 mm (23 in) in diameter and is 1250 m (4100 ft) in length.

H_2S is also emitted from the cooling tower stacks so it is impossible to vent all the H_2S away from the power house. The prevailing winds usually carry the cooling tower plumes away from the power house. The cooling tower is 100 m (328 ft) from the plant and is aligned with the direction of the prevailing winds.

Power Plant Equipment, Electrical Apparatus The electrical equipment is susceptible to corrosive attack by hydrogen sulfide; special precautions are taken for the protection of this equipment. Most switch-boards, including the control room main switch-board, are installed in enclosures provided with air conditioning systems. These a/c systems are fitted with activated carbon filters filled with activated alumina beads impregnated with potassium permanganate. The electrical contacts on the high-voltage side at the substation are plated with a noble metal alloy.

Unit Outages Operating records at the plant were reviewed to accumulate the annual forced and programmed outage hours. There were a total of 344 outage hours; from the time Units

No. 1 and 2 began commercial operation until the end of 1978. The small number of outage hours shows the good availability and reliability of the power plant equipment. The equipment performance was a result of careful design, material selection and maintenance.

The following table Outage Hours shows forced and programmed outages for Units No. 1 and 2. Forced outages are defined by the CFE as non-scheduled shutdowns initiated by electrical relay actions. Programmed outages are controlled unit shutdowns to correct a mechanical problem.

OUTAGE HOURS

Year	Unit	Forced	Programmed	Total
1974	1	9	12	21
1974	2	8	41	49
1975	1	29	20	49
1975	2	18	83	101
1976	1	2	35	37
1976	2	14	14	28
1977	1	-0-	22	22
1977	2	-0-	6	6
1978	1	-0-	7	7
1978	2	-0-	24	24

The programmed outages were necessary to make repairs of associated material damaged by corrosion. Oil coolers, hydrogen coolers and steam jet air ejectors were the items that experienced failures.

Power Plant Maintenance The turbine lubricating oil coolers were furnished with aluminum tubing. Corrosion of the tubing was severe and the CFE changed the tube material to titanium beginning in 1974. The electric generator hydrogen coolers were also furnished with aluminum tubing which had to be replaced with titanium.

The cooling water supply headers for the hydrogen coolers were furnished as stainless steel by the CFE. The supply and return piping, connecting the headers and coolers, was furnish by Toshiba as low carbon steel. This piping was replaced with stainless steel during programmed outages or annual maintenance.

The discharge (diffuser) tubes of the air ejectors were furnished as carbon steel. This material had to be replaced with stainless steel because of severe corrosion perforations caused by the non-condensable gases. The plant design had three sets of ejectors for each unit but the manifold shut-off valves for the ejectors failed to close and the unit had to be shutdown to do repairs on the ejector set.

Power Plant Maintenance Schedule Major maintenance was conducted on an annual basis per recommendations of the turbine manufacture, Toshiba. During the turbine internal annual inspections the CFE found scaling in the nozzles and on the blading of the turbine. The deposits were removed by mechanical cleaning and the turbine internals were examined with a dye penetrant test.

No fissures were detected in the turbine internals but the scaling continued to form during the running period. The scaling was caused by carry-over in the steam from vapor/liquid separators at the well heads. The scaling restricted steam flow and decreased the unit output about 10 percent during the course of one years operation.

The vapor/liquid separator is shown in Figure No. 4. The length of the internal vapor outlet pipe was increased and the separation improved. The better quality of steam was evident during the annual overhauls. The internal condition of the turbine showed less scaling relative to prior inspections. This internal condition prompted the CFE to extend the time between overhauls. The following table shows the maintenance schedule for Units No. 1 and 2 since start-up in 1973.

Year	Unit	Operating Hours Between Overhaul	Maintenance Period
1973	2	Start Operation 4/1973	
1973	1	Start Operation 9/1973	
1974	2	8325	39 days
1974	1	9380	42 days
1975	2	7533	27 days
1975	1	7937	32 days
1976	2	7169	26 days
1977	1	12119	32 days
1978	2	15596	36 days
1979	1	16943	36 days
1979	3	Start Operation 3/1979	
1979	4	Start Operation 4/1979	

Unit No. 2 is scheduled for major maintenance in February 1980 after 16,000 hours of operation, but maintenance is delayed until April 1980 to permit maintenance of Unit 4 earlier than planned.

Summary The CFE geothermal flash steam power plant has achieved a high capacity factor during five years of commercial service. Plant operation, design and maintenance have contributed to this geothermal energy electric production accomplishment.

Cerro Prieto operation as a base load geothermal plant has been stable and relatively simple compared to running a fossil fuel fired steam plant. Base load operation eliminates the thermal cycling stress problems that are encountered in peaking or load following steam plants. The plant personnel are confident that the plant capacity factor will remain at its high level for the next five year period.

Careful selection of material compatible to the geothermal steam is a major design consideration. Plant equipment can be designed with redundant systems when there is evidence that corrosive elements in the geothermal steam may cause problems that require maintenance outages. Design of the redundant system should insure uninterrupted operation of generating unit with emphasis on the capability to isolate the redundant system should it require maintenance.

Maintenance by plant personnel should be prompt, cost effective, and done with the goal that the repair problem will not occur again.

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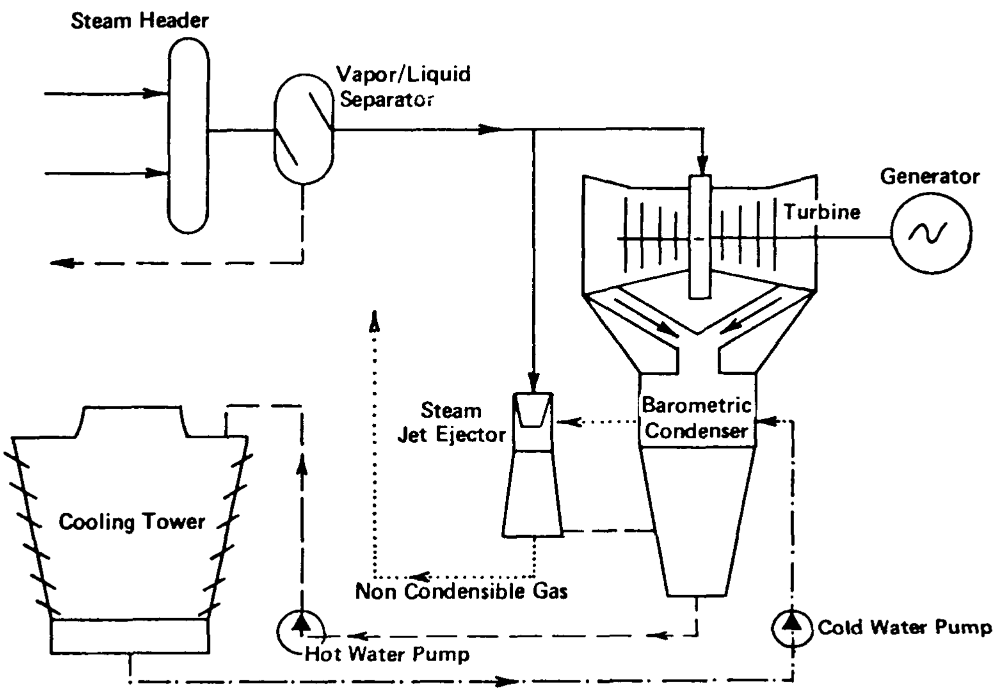
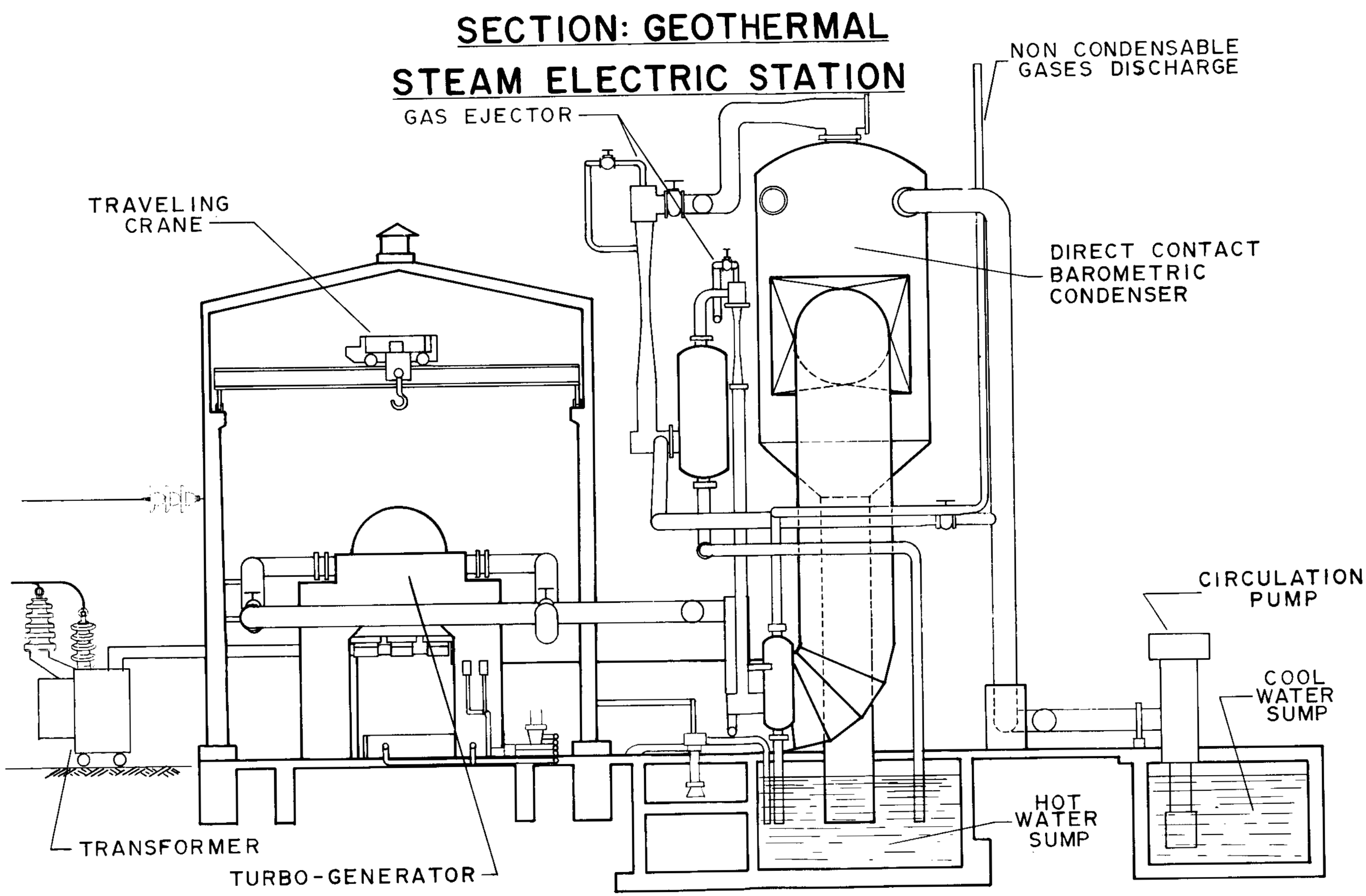


Geothermal Power Plant

———— Steam
— — — Hot Water
·—·—·— Cold Water
·········· Non Condensable Gases

Figure No. 1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STEAM ELECTRIC STATION
GAS EJECTOR
NON CONDENSABLE
GASES DISCHARGE
TRAVELING
CRANE
DIRECT CONTACT
BAROMETRIC
CONDENSER
CIRCULATION
PUMP
COOL
WATER
SUMP
HOT
WATER
SUMP
TRANSFORMER
TURBO-GENERATOR

Figure No. 2

BAROMETRIC CONDENSER

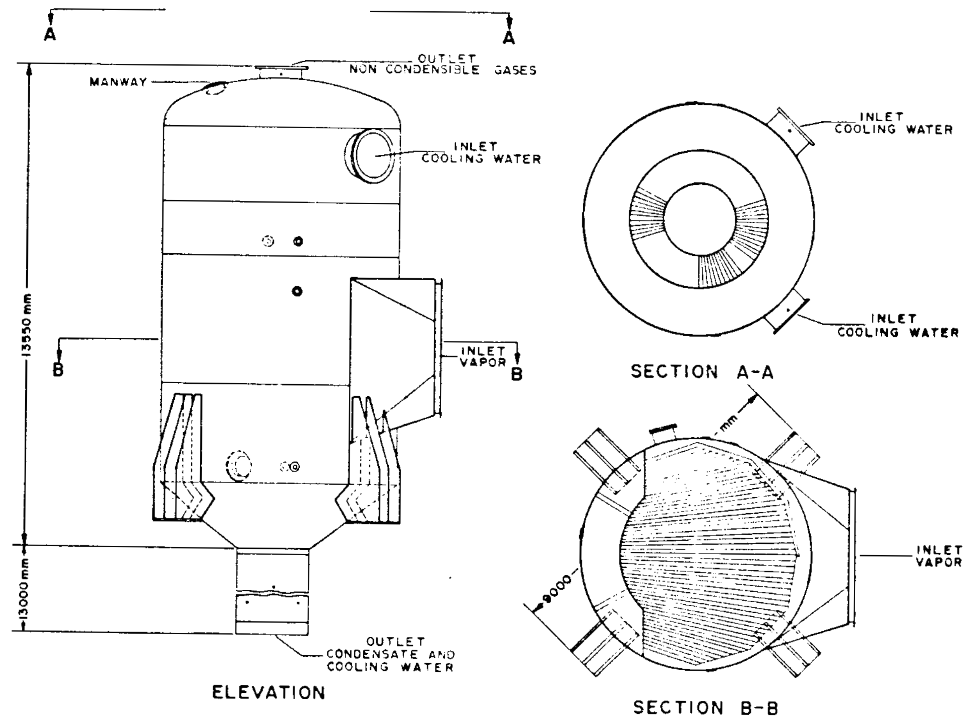

Figure No. 3

CENTRIFUGAL SEPARATOR

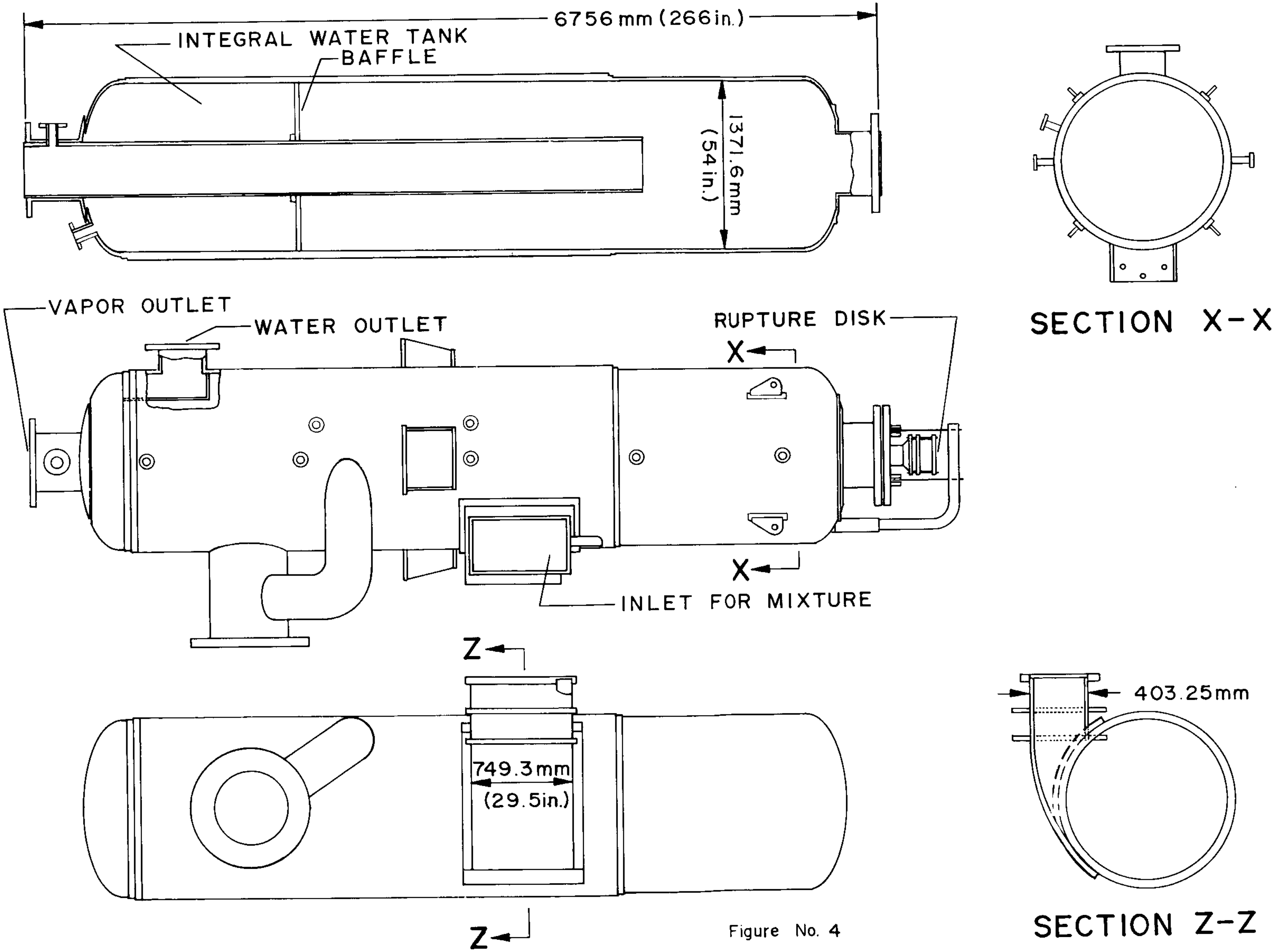

Figure No. 4