

Geothermal Power Plant Condensers in the World

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ABSTRACT

The condenser is one of the heat exchangers used in power plant cycles and is assumed to generally be the most important. This importance results from the essential job this equipment has. This paper deals with studying condenser types briefly and then reviewing the major condenser types in geothermal power plants around the world based on power plant site aerology. Data has been taken from reports, Affiliated Organizations and websites of private and public organizations involved in geothermal development

1. INTRODUCTION

Operation cycles used in geothermal power plants have many components, but there are four components which are common to all power plants. In these cycles, steam is separated from the flow coming from a well in a separator, its remaining moisture is removed using a demister and therefore high temperature and pressure steam is produced. This steam is then expanded in a turbine to produce electricity from a generator that is connected to the turbine. The steam from the turbine is then condensed back into water in the condenser. The pump then returns the water to the injection wells.

A condenser is a type of heat exchanger in which vapors are transformed into liquid state by removing the latent heat with the help of a coolant such as water. The cooling water is usually obtained from a cooling tower that recirculates a portion of the condensed steam after it has been cooled by partial evaporation in the presence of a moving air stream. This means that geothermal flash-steam plants do not need a significant supply of cooling water, a major advantage in areas that are arid. However, a small amount of fresh water is needed to provide for replacement of tower blowdown in wet cooling towers. A condenser is normally used on all geothermal plants to increase the power by maximizing pressure drop across the turbine. Condensing the steam at the turbine exhaust creates a vacuum (0.15 atm), thus maximizing the pressure drop and power output.

2. CONDENSER FUNCTION

The main purpose of the condenser is to maximize turbine efficiency by maintaining a proper vacuum by condensing steam, removing dissolved non condensable gases from the condensate and conserving the condensate for re-injection or as feed water for the cooling tower. As the operating pressure of the condenser is lowered (vacuum is increased), the enthalpy drop of the expanding steam in the turbine will also increase. This will increase the amount of available work from the turbine (and thus electrical output). By lowering the condenser operating pressure, the following will occur: 1) increased turbine output, 2) increased plant efficiency and 3) reduced steam flow (for a given plant output). It is therefore very advantageous to operate the condenser at the lowest possible pressure (highest vacuum).

Geothermal steam contains non-condensable gases such as hydrogen sulfide (H_2S), carbon dioxide (CO_2), methane (CH_4) and others in very small amounts. Uncontrolled venting of steam releases all these gases to the atmosphere. Under normal conditions, these gases are isolated in the condenser, drawn into the ejectors and, if necessary, treated before release to the atmosphere. There are many reliable, cost-effective means for removing H_2S if the amount that would be vented exceeds regulated limits. The CO_2 that is released from flash plants is not abated but constitutes a relatively minor source of greenhouse gases: flash plants emit about 0.06 kg/kWh compared with 0.59 kg/kWh for a natural-gas-fired gas turbine and 1.13 kg/kWh for a coal-fired plant.

The reason for removing air/gas is that these gases will increase the operating pressure of the condenser. This rise in pressure will decrease the turbine output and efficiency. The gases will blanket the outer surface of the tube which will severely decrease the heat transfer out of the steam to the circulating water. Again, the pressure in the condenser will increase. The corrosiveness of the condensate in the condenser increases as the oxygen content increases. Oxygen causes corrosion, mostly in the steam generator. Thus, these gases must be removed in order to extend the life of cycle components

3. CONDENSER TYPES

Condensers may be classified into two main types: 1) those in which the coolant and condensing vapor are brought into direct contact also known as Direct Contact Condensers and 2) those in which the coolant and condensate stream are separated by a solid surface, usually a tube wall, also known as Surface Condensers. These types can be further divided into different types such as: Double Pipe and Multiple Pipe, Plate Condensers, Air-Cooled Condensers, Compact Condensers, Shell & Tube, etc. The main subdivisions of condensers are shown in Figure 1.

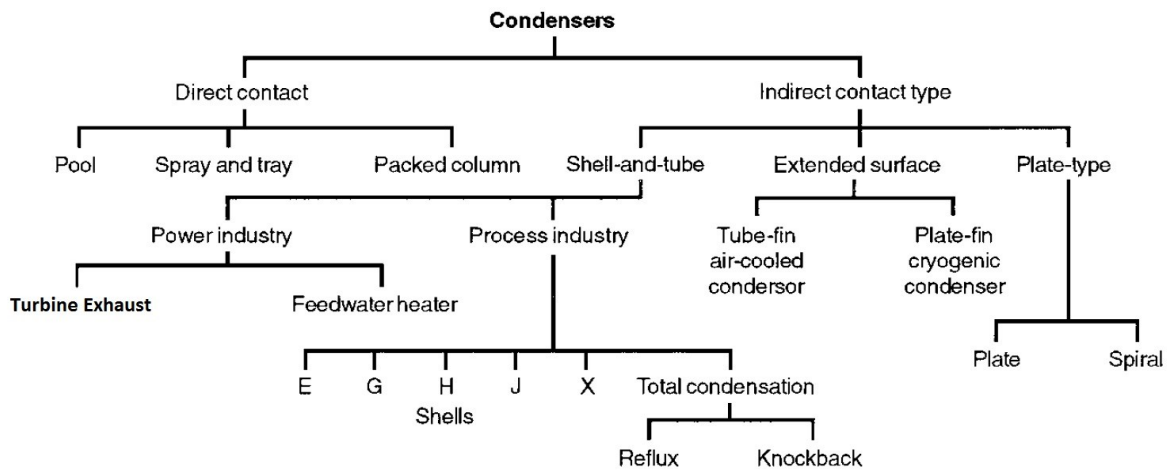


Figure 1. The main subdivisions of condensers.

3.1 Direct Contact Condensers

In direct contact condensing, the coolant is sprayed directly into the condensing vapor. This method is sometimes used for intermediate heat removal from distillation and absorption columns by means of pump arounds. While direct contacting provides a high rate of heat transfer with low-pressure drop, it is obviously limited to applications in which mixing of coolant and condensate is permissible. It is less expensive than surface condensers.

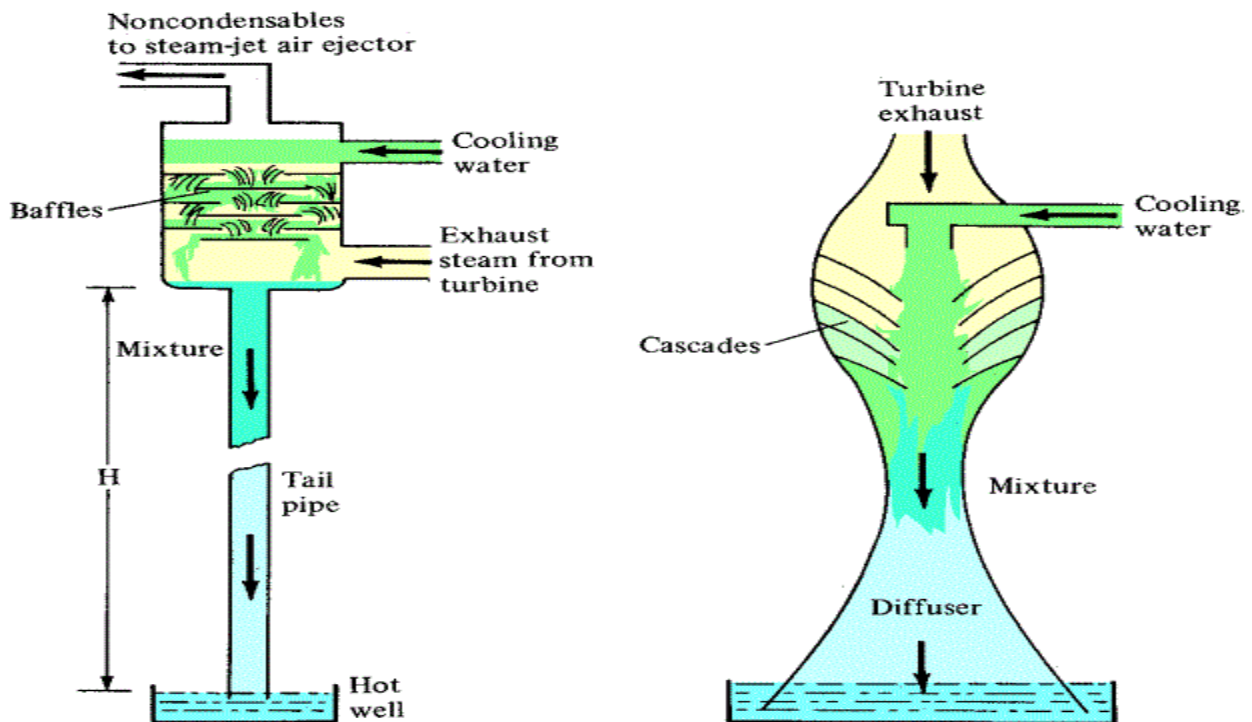


Figure 2. Early direct-contact condensers. (Left Pic) diffuser or jet (Right Pic) barometric.

3.2 Surface Condensers

Surface condensers are tubular exchangers, but their construction differs somewhat from shell and tube equipment used to condense process vapors. They are most often designed for vacuum operation on the shell (steam) side, and hence must handle a large volumetric flow rate of vapor with very low-pressure drop. Smaller units may have circular cross-flow shells similar to X-shells, but larger units usually employ a box-type shell. The main heat transfer mechanisms in a surface condenser are the condensing of saturated steam on the outside of the tubes and the heating of the circulating water inside the tubes. Thus for a given circulating water flow rate, the water inlet temperature to the condenser determines the operating pressure of the condenser. As this temperature is decreased, the condenser pressure will also decrease. As described above, this decrease in the pressure will increase the plant output and efficiency. The non-condensable gases consist of mostly air that has leaked into the cycle. These gases must be vented from the condenser. Surface type is necessary if non-condensable gases are treated to limit emission of H₂S and SO₂. Here we try to explain a little more about rather more important subdivisions of surface condensers.

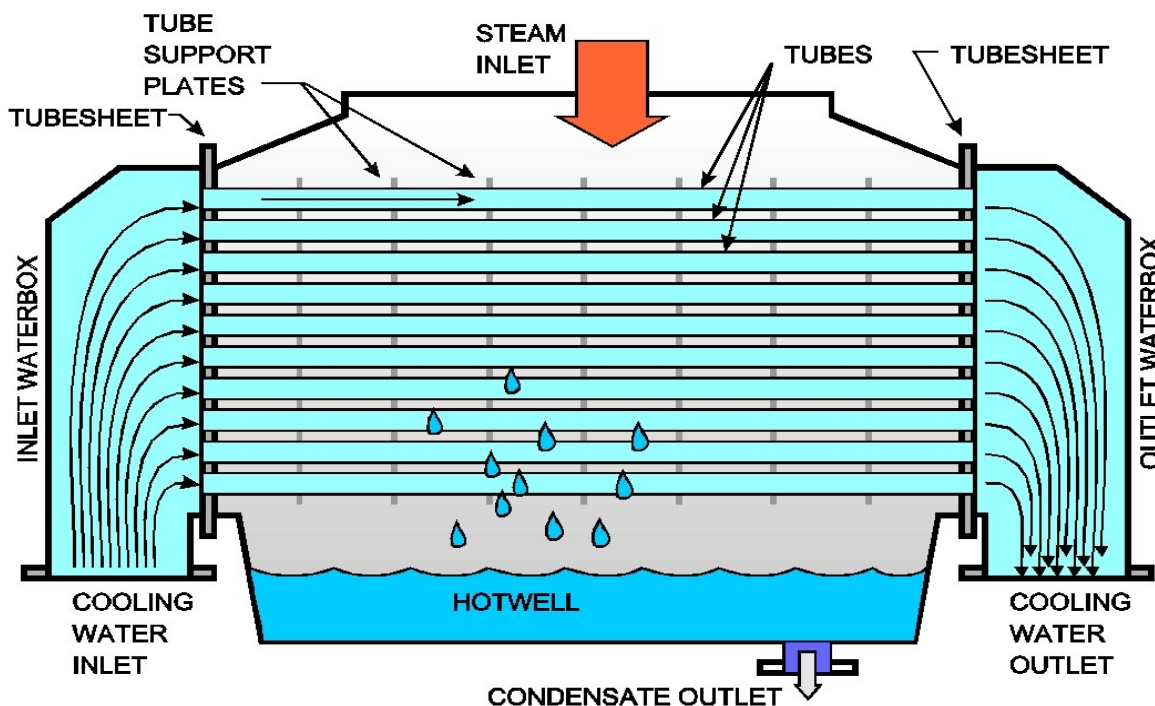


Figure 3. A power plant surface condenser.

3.2.1 Air Cooled Condensers

In this type of condenser the condensing vapor flows inside a bank of finned tubes and ambient air blown across the tubes by fans serves as the coolant. Air-cooled condensers are used where water is scarce (such as desert climates). Their efficiency can reach up to 30% although it is lower in summer due to high dry-bulb temperature. Natural draft cooling towers are used at some plants such as Larderello, Matsukawa, and Ohaaki, NZ. These have lower operating costs and reliable, continuous operations compared to mechanical draft.

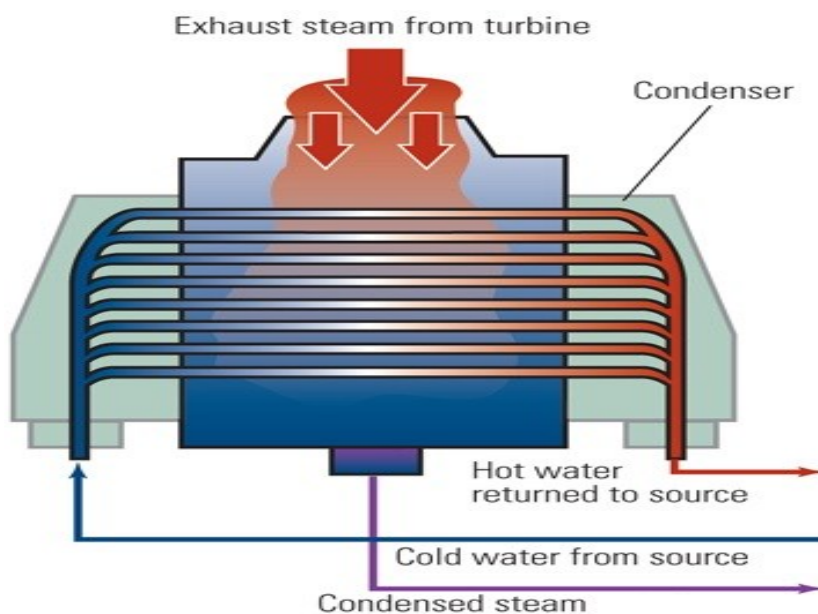


Figure 4. Air cooled condenser

3.2.2 Gasketed Plate Condensers

The plate heat exchanger is basically a series of individual plates pressed between two heavy end covers. The entire assembly is held together by the tie bolts. Individual plates are hung from the top carrying bar and are guided by the bottom carrying bar. For single-pass circuiting, hot and cold side fluid connections are usually located on the fixed end cover. Multi-pass circuiting results in fluid connections on both fixed and moveable end covers.

The plate heat exchanger is the most widely used configuration in geothermal systems of recent design. A number of characteristics particularly attractive to geothermal applications are responsible for this. Among these are:

1. Superior thermal performance.
Plate heat exchangers are capable of nominal approach temperatures of 10 °F compared to a nominal 20 °F for shell and tube units. In addition, overall heat transfer coefficients (U) for plate type exchangers are three to four times those of shell and tube units.
2. Availability of a wide variety of corrosion resistant alloys.
Since the heat transfer area is constructed of thin plates, stainless steel or other high alloy construction is significantly less costly than for a shell and tube exchanger of similar material.
3. Ease of maintenance.
The construction of the heat exchanger is such that, upon disassembly, all heat transfer areas are available for inspection and cleaning. Disassembly consists only of loosening a small number of tie bolts.
4. Expandability and multiplex capability.
The nature of the plate heat exchanger construction permits expansion of the unit should heat transfer requirements increase after installation. In addition, two or more heat exchangers can be housed in a single frame, thus reducing space requirements and capital costs.
5. Compact design.
The superior thermal performance of the plate heat exchanger and the space efficient design of the plate arrangement results in a very compact piece of equipment. Space requirements for the plate heat exchanger generally run 10% to 50% that of a shell and tube unit for equivalent duty. In addition, tube cleaning and replacing clearances are eliminated (Kevin D, 1998).

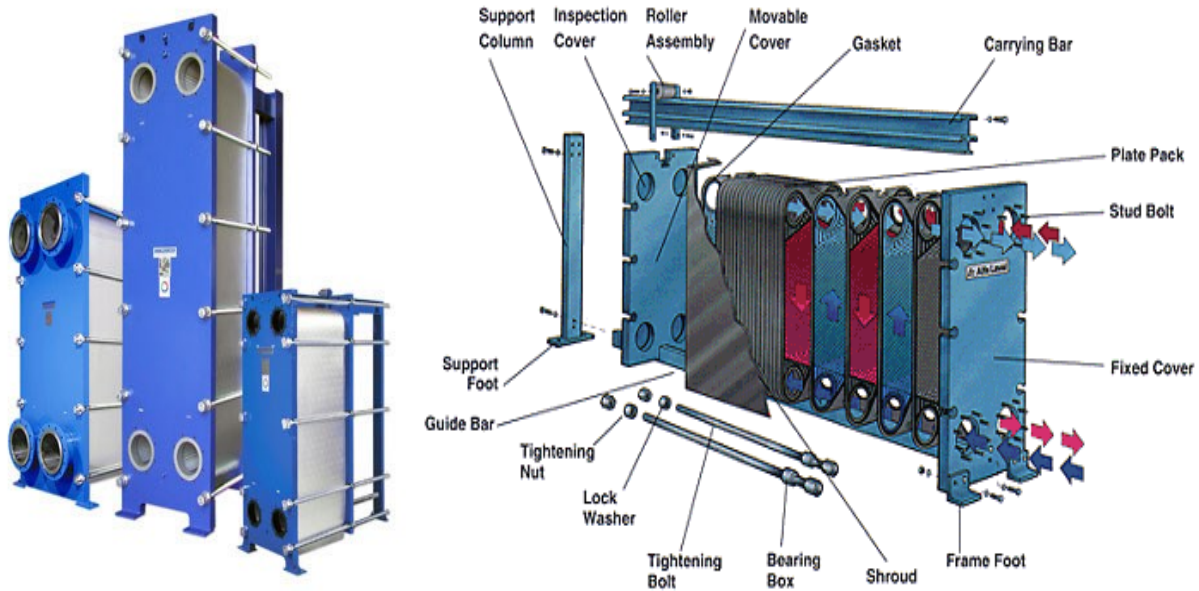


Figure 5. Gasketed Plate Condensers.

4. CONDENSER TYPE APPLICATION

Practically all types of heat exchangers have been used for condensation. Although shell-and-tube and air-cooled are the most common in the process industries, plate and spiral-plate types are gaining in popularity. An air-cooled condenser (ACC) is often selected since makeup water for cooling towers is scarce at many geothermal sites. Because the criteria for selecting shell-and-tube configurations vary and are sometimes arbitrary, an awareness of design advantages and disadvantages can contribute to investment savings and/or improved operation.

In single flash power plants the steam from the turbine is condensed by means of either a surface type condenser or in a direct-contact condenser of either the barometric or low-level type. Most plants now employ surface condensers in which the geothermal steam passes through the shell side and cooling water passes through the tube side. This maintains physical and chemical separation between the geothermal steam and the cooling water, and allows more effective removal and treatment of non-condensable gases. Gases such as carbon dioxide and hydrogen sulfide exist within the natural steam and do not condense at the temperatures reached in the condenser. Therefore unless they are removed they will increase the overall pressure in the condenser and lower the turbine power output. Steam jet ejectors with after condensers and/or vacuum pumps are used for this purpose. In double flash cases, the turbines could exhaust to a common condenser just like above.

In dry steam power plants the condensers can be either direct-contact (barometric or low-level jet) or surface-type (shell-and-tube). For small units, it is often advantageous to arrange the turbine and condenser side-by-side, rather than the more usual condenser-below-turbine arrangement seen in most power plants. The non-condensable gases in the steam are isolated in the condenser and removed by means of vacuum pumps or steam-jet ejectors, and they can be treated to remove hydrogen sulfide, if it is present at objectionable levels. The sulfur from certain types of abatement systems is in pure form and may be sold commercially or disposed of in an appropriate landfill. The excess condensate from the cooling tower is reinjected as is any liquid trapped from the steam transmission pipelines (Ronald D, 2007).

5. GEOTHERMAL POWER PLANT CONDENSERS

Here are the results which have been gathered for some of the condenser types in geothermal power plants.

Table 1. Survey of condensers used in geothermal power plants worldwide.

Column	Power Plant Name	Country	Type	Capacity	Condenser	Source
1	SALAK Unit 4&5&6	Indonesia		3×55 MW	Surface	SPX (Blacke Durr) Catalogue
2	Hellisheidi 7 unit 4×45(Mitsubishi) 33(Toshiba) 2×45(Mitsubishi)	Iceland	Single Flash	4×45 MW (Unit 1-4)	Surface	SPX (Blacke Durr) Catalogue & SPX(Blacke Durr) 2 Catalogue
3	Nesjavellir 4×30	Iceland	Single Flash	4×30 MW (3 Mitsubishi)	Surface (Tubular)	SPX (Blacke Durr) 2 Catalogue & 0242 Paper of the WGC2010 page 1, section 1
4	Tizate 1+2	Nicaragua (San Jacinto)	Single Flash	2×36 MW (Fuji)	Direct contact	SPX (Blacke Durr) 2 Catalogue
5	Germencik	Turkey	Double Flash	1×45 MW (Mitsubishi)	Surface	SPX (Blacke Durr) 2 Catalogue
6	Olkaria I	Kenia	Single Flash	89 MW	Jet Condenser with wet cooling tower	2665 Paper of the WGC2010, page 8
7	Steamboat 2 & 3	America (Nevada)	Binary	43 MW winter 18 MW summer	Air-cooled fin- fin condenser	2655 Paper of the WGC2010, page 1
8	Paushetsky	Russia	Binary	2.5 MW Pilot	Surface (Shell & Tube)	2646 Paper of the WGC2010
9	Svartsengi unit 5	Iceland	Binary	30 MW	Surface (Shell & Tube)	2645 Paper of the WGC2010, page 2
10	Svartsengi unit 3	Iceland	Back Pressure	6 MW	-	2645 Paper of the WGC2010, page 2
11	Svartsengi unit 6	Iceland	- 4 Stage Back Pressure -10 Stage Condensing Turbine(Single Flash)	33 MW	water cooled Shell & Tube Condenser	2645 Paper of the WGC2010, page 2 & SPX (Blacke Durr) 2 Catalogue
12	Svartsengi (pp4)	Iceland	pp4 (Both ORC): 1) Ground water 2) 4 Air-Cooled asynchronous	2) 3×1.2 MW 4×1.2 MW	2) 4 Air-Cooled asynchronous	0643 Paper of the WGC2010, page 1
13	Reykjanes Unit 1-3	Iceland	Single Flash	50 MW	Shell & Tube with sea water	2645 Paper of the WGC2010, page 3

14	Upper Mahiao	Philippines	Combined (Single & Binary)	1 MW	Air-cooled condenser (no cooling tower-->خلاف عرف)	2707 Paper of the WGC2010, page 1
15	Nouva san Martino	Italia	Dry steam	40 MW	Direct Contact	0140 Paper of the WGC2010, page 2, section 2.1
16	Reykjanes	Iceland	Single Flash	2×50 MW	Sea water cooled condenser	0124 Paper of the WGC2010, page 5, section 5.3 & 0643, page 1
17	Kizilder	Turkey	Single Flash	20.4 MW	Direct Contact	0224 Paper of the WGC2010, page 1, section 1
18	Kamojang Unit 4	Indonesia	Dry Steam	63 MW	Direct Contact	0623 Paper of the WGC2010, page 5, section 5.1
19	Western Geopower plant	San Francisco	Single Flash	30.8 MW	Surface-wet cooling Tower	2505 Paper of the WGC2010, page 1, section 1
20	Wayang Windu Unit 1	west java Indonesia	Single Flash	110 MW	Direct Contact spray type condenser ----- Counter Flow Forced Draght with motor driven tower	2619 Paper of the WGC2010, page 1, section 1.1
21	Wayang windu	Indonesia	Binary	2 KW	Surface (Shell & Tube)	2663 Paper of the WGC2010
22	Miravalles Unit 3	Costa Rica	Single Flash	29 MW	Direct Contact Side by Side	2604 Paper of the WGC2010, page 3, Table 2
23	PGM-29 Wellhead unit	Costa Rica	Single Flash	5 MW	- (Atmospheric Exhaust)	2605 Paper of the WGC2010, page 4, Table 2

24	Kawerau	Newsland	Double Flash	100 MW	Direct Contact spray Type ----- Counter Flow Mechanical draft Type	2621 Paper of the WGC2010
25	Cerro Prieto I, Units 1-4	Mexico	single flash	37.5 MW	elevated, barometric, direct-contact	1973 (1 + 2), 1979 (3 + 4)
26	Cerro Prieto I, Units 5	Mexico	Double flash	30 MW	low-level, spray-tray, direct-contact	1981
27	Cerro Prieto II and III	Mexico)	Double flash	110 MW	low-level, spray-tray, direct-contact	1982 (II), 1983 (III)
28	Cerro Prieto IV(unit 1-4)	Mexico	single flash	100 MW	low-level, spray-tray, direct-contact	2000

6. CONCLUSION

As you can see many power plants designers preferred the direct contact condensers in modern power plants, probably due to the cost effective and other advantages which this type of condensers has. Also there are fouling problems and scaling which is critical in geothermal power plants and limits the designers due to the maintenance requirements of the surface condensers.

REFERENCES

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