WATER COOLING FOR INDUCTION SYSTEMS: INSIDE AND OUT

Water-cooling circuits are the most neglected item in induction maintenance causing the most down time and damage. Common sense installation and maintenance practices can help reduce unexpected down time, there by increasing profits for the user.

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Induction water-cooling systems are as diverse as your imagination. Hybrid combinations continue to be developed by companies that want to go green, save energy, and reduce water consumption and costs. Over the years, different OEMs and users have developed various systems depending on location, water costs, real estate, and local building code restrictions. The types and combinations discussed in this article are the most predominant. Today, cooling systems usually consist of a closed-loop recirculating system to cool the power supply, heat station, coils, bus, and leads. All use some sort of water-to-water heat exchanger in conjunction with plant water (dirty water) supplied by a cooling tower, radiator/fan, refrigeration type chillers, city water, well water, and geothermal field. High-quality, low-conductivity water is used in the closed-loop system (clean side) to cool the power supply. Plant water (typically cooling-tower water) is considered the dirty side of the heat exchanger, but it may be acceptable for cooling the power supply if the water quality is within limits and all plumbing is nonferrous.

This paper is NOT intended to replace your OEM equipment manual, which usually has a section on water cooling-system installation, maintenance, and recirculating-water characteristics.

Fig. 1 — Water recirculating system for cooling an induction power supply including stainless steel pump, copper pipe, cartridge filter, nonferrous plate-type heat exchanger, and temperature control to prevent condensation.

Recirculating Water Systems for Power Supplies

Closed-loop recirculating water systems are the life blood of an induction system. They supply controlled temperature cooling for the power supply, capacitor heat station, water-cooled leads and bus, and the induction coil (Fig. 1). The systems consist of a holding tank, pump, filter cartridge,

Process plant water-cooling system relative costs

Type	Investment cost	Operating cost	Maintenance	Lowest achievable temperature, °F
Air-to-air (dry)	$$	$	$$	105
Closed-loop evaporative	$$$	$$$	$$$	85
Open-loop evaporative	$$	$$	$$$$	85
Refrigeration chiller	$$$$	$$$$	$$	65

*Member of ASM International and member, ASM Heat Treating Society heat exchanger, and temperature controller to prevent condensation. Recirculating water that is too cold (below the dew point) must be avoided to prevent condensation in the power supply, heat station, and coil, and to prevent damaging electrical arcs.

It has long been understood that as much as 90% of induction heating-system problems are water related. High-conductivity water is usually the culprit, which causes cooling-system and power-supply erosion due to electrolysis. This reaction causes the erosion of critical copper components, and the eroded debris collects at the location of the opposite polarity, which reduces water flow in that circuit (Fig. 2). Lower water flow results in higher operating temperatures of the device, leading to premature failure due to overheating. This is most common in certain water-cooling paths where high electrical current potentials are present, such as SCRs, diode heat sinks, chokes (reactors), and transformers referred to as the dc link.

For example, one side of an SCR heat sink is positive and the other side is negatively charged at the exact moment in time. Both sides of the SCR share the same water, and the hose length between these electrical potentials isolates the high voltage from the next component in the water circuit and from the electrically grounded water manifold. As the conductivity of the water increases, electrical leakage occurs down the water path, because electrical current always takes the path of least resistance to ground, or its opposite polarity. Voltages are always looking for their return path to ground. The conductive water makes the hose length seem shorter, which makes the electrical leakage current run more easily to ground, and electrolysis occurs faster. A hose can be thought of as a water-cooled resistor. Ideally, when the hose is new, the resistance is very high (in the multiple Mohms). As water quality deteriorates, the effective resistance of the hose decreases allowing more leakage current to flow.

Some OEMs recommend different water types (the most common being reverse osmosis, or RO, deionized, or DI, and distilled), and most recommend an additive such as glycol. A 30% percent ethylene glycol (uninhibited, nonconductive type) mixed with water serves as a buffer and has a filming agent that keeps the water from becoming too aggressive to prevent corrosion. Also, it protects from

Fig. 2 — Calcium-clogged water paths due to high conductivity water.

freeze damage if heat is lost in the plant for an extended period of time. Ajax TOCCO offers MAGNE-COOL premixed water and glycol solution designed specifically for use in induction applications.

Water that has conductivity that is too low is just as corrosive. RO and DI processing systems can generate water at 0 to 10 μmho/cm. This condition is too "hungry" and causes similar corrosion in the DC link. Circuits that use ac voltages still require the same high quality water.

Closed-loop systems that cool the power supply should be constructed of nonferrous materials, such as PVC, copper, brass, nonmagnetic stainless steel, and nonconductive rubber hose. Never use black iron, galvanized, carbon steel, or garden hose in the plumbing of the power supply cooling circuits. One single piece of any ferrous material in the closed loop will cause water conductivity to rapidly rise and clog the small paths in the power supply. When replacing hose, never shorten the hose length as the length is pre-engineered by the OEM. The length is based on recommended water conductivity and the amount of voltage present at the device being cooled. When replacing hose clamps, use only stainless steel with stainless screw posts.

The use of lake, well, river, or city tap water directly into an induction power supply or heat station can cause severe damage. Even good quality water by its nature will breakdown as it reacts with copper over time. Quarterly checks are recommended for pH and conductivity. Water in the power supply closed loop should be changed every year to 18 months depending on the conductivity readings. Drain, flush with clean water, and refill on a scheduled maintenance program. Just adding clean make-up water may not keep the conductivity at low enough levels. When refilled, check the pressure differential switch and its function, and always maintain a minimum of 30 psi differential across the system, which has become the industry standard. To diagnose plugged paths, an infrared (IR) survey at full power rating can detect overly hot water paths, and it is especially useful on large power supplies having dozens of water paths.

Some older power supplies used sacrificial anodes (also know as "targets") to protect the DC link. The targets were made of tungsten or stainless steels and over a couple of years dissolved into the water. Their use was found to cause clogging even with acceptable water quality. These have fallen out of favor in the past several decades and quality water is now the norm. Another trend is toward using smaller holding tanks with fewer gallons of water in the system, resulting in less to clean and maintain. Smaller, larger capacity heat exchangers have helped this trend evolve.

During cooling-system installation, it is extremely important to place air bleeder vents at the highest point of the plumbing to remove trapped air. Air is not a good conductor of heat and if it becomes trapped in the induction equipment can cause component failure or reduced component life. During yearly maintenance, when the system is drained and flushed, air must be bled off after the system is refilled.

The following is an example of a cooling-water specification for recirculating water used to cool induction power supplies that do not use targets or sacrificial anodes.

Total hardness ($CaCO_3$)	15 ppm
Total dissolved solids	25 ppm
Conductivity	20 to 50 μmho/cm
Max suspended solids	10 ppm
pH	7.0 to 7.5

The following is an example of a cooling water specification for recirculating water used in an induction power supply that has replaceable targets or sacrificial anodes or for heat stations and coil cooling.

Total hardness ($CaCO_3$)	100 ppm
Total dissolved solids	200 ppm
Conductivity	50 to 300 μmho/cm
Max suspended solids	10 ppm
pH	7.0 to 7.5

Always check your OEM manual for their recommendations.

Cooling Towers

Cooling towers are designed to remove heat from water and dissipate the heat into the atmosphere. Of the many types available, three most commonly used types are air-cooled, closed-loop, and open-loop evaporative towers.

Air-cooled heat exchanger-tower systems consist of a motor and pump with an expansion tank, and tower (which consists of cooling tubes, fins, and fans). These air-cooled systems are very low maintenance compared with evaporative systems, but they lack the cooling capabilities of evaporative towers.

Pressurized closed-loop cooling towers require the use of glycol to prevent freeze damage in the pressurized bundle, and they have a collection pan heater to prevent freezing in the pan area. Heat tape is commonly used on the tower piping to prevent pipes from freezing. Open towers with a gravity drain to an inside tank do not require glycol, nor is there a pan heater. Evaporative towers require more maintenance than dry towers or geothermal systems.

It is necessary to analyze the glycol in cooling tower systems yearly for pH level, inhibitor, and freeze protection, and make adjustments according to the OEM specifications. All cooling tower types need a yearly "spring cleaning" with an appropriate aluminum fin cleaner and low-pressure rinse to remove dirt, and calcium, and to restore 100% cooling capacity for the hot summer months.

The following is suggested water quality requirements for both dry and evaporative cooling towers.

Total hardness ($CaCO_3$)	100 ppm
Total dissolved solids	200 ppm
Conductivity	20 to 300 μmho/cm
Max suspended solids	10 ppm
pH	7.0 to 7.5

Always check your OEM manual for their recommendations.

Air-Cooled Heat Exchangers

Air-cooled heat exchangers cool by means of fans blowing air across a cooling bundle made of stainless steel or copper tubing. The air-to-air coolers are capable of cooling the recirculating water to within 5°F of ambient air temperature; i.e., 95°F water temperature on a 90°F day. Major advantages include low maintenance and low horsepower, which equals the lowest operating cost. A disadvantage in heat-treating applications during daytime hours in hot summer months is the need for a trim cooler with a water-to-water heat exchanger to control quench temperatures down to an acceptable 90°F or lower quench temperature.

Fig. 3 — Air-cooled tower with top fans.

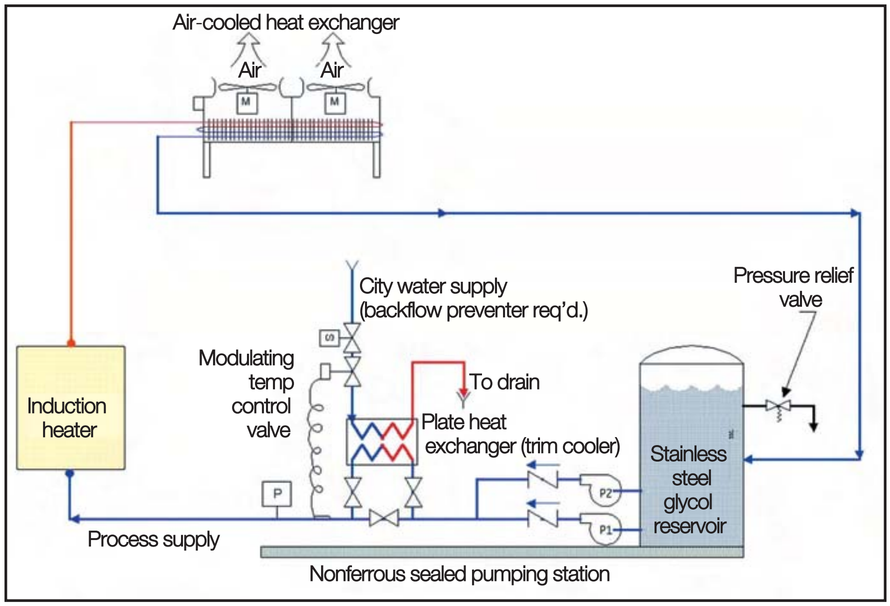

Fig. 4 — Schematic of air-cooled tower with a water-to-water trim cooler. Courtesy Dry Coolers Inc., Oxford, Mich.

The importance of placement or positioning of the air-to-air type cooling towers is often overlooked. Ideal placement is on the north side of the building in the shade of the building and out of direct sunlight, facing an open field (Fig. 3). This is not always possible, but placement on the south or west side in direct sunlight will reduce the ability of the tower to dissipate heat. Placement on a black roof is not recommended due to superheated air rising off the hot roof and direct sunlight, which raise the temperature of the enclosure. Ambient air temperature can increase by 5 to 10°F on a roof, which makes placement of these towers on a roof impractical without heavy trim cooling or extra large size. Elevating the air cooler off the roof as far as possible also helps. The main consideration is to get fresh, cool air into the air cooler.

Air-Cooled Heat Exchangers with Trim Cooler

These systems use a dry-type tower with a temperature-regulated source of additional cooling (Fig. 4). The trim is only used when the air-cooled tower cannot reduce the water temperature low enough; usually in the summer during the afternoon hours when the ambient temperature exceeds the input temperature of the power supply or quench systems by 10°F. The induction power supply will fault on a "hot-water input" and shut off. The additional trim can be a plate type heat exchanger with city/well water cooling the dirty side of the heat exchanger and down the drain. Another type of

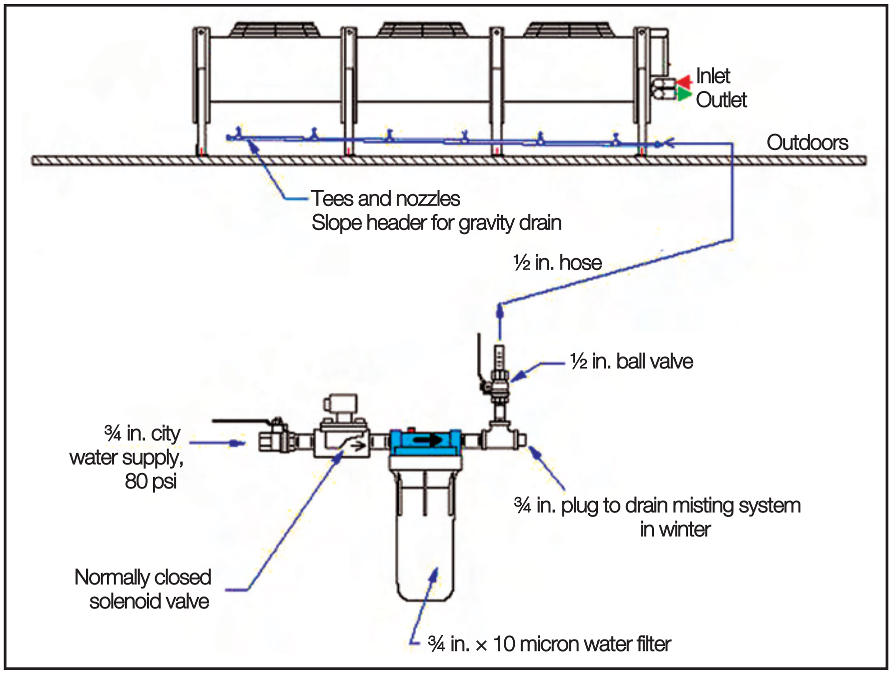

Fig. 5 — Air-cooled tower that uses an atomized mist assist option. Courtesy Dry Coolers Inc., Oxford, Mich.

Fig. 6 — Counter-flow closed-loop pressurized evaporative cooling tower; requires a pan heater.

trim is a compressor/chiller with the same type of plate or tube and shell heat exchanger. The trim atomized mist assist shown (Fig. 5) is only needed on extremely hot days in the summer when temperatures reach 90°F. The water used in the mist assist should be good filtered city water or better. Most dry towers can operate without trim use in winter, spring, and fall and during summer nights when ambient temperatures are cooler.

Closed-Circuit Evaporative Cooling Towers

Closed-circuit pressurized cooling towers are used extensively to cool plant process water using a closed pressurized recirculating system. Scale and corrosion formation can be greatly reduced with a closed tower compared with an open type tower. Eliminating scale and sludge formation is critical in the water-cooling bundles (tubes). Use of a closed circuit tower prevents the water in the tubes from coming into contact with the spray water or atmosphere air flowing across the tubes.

Evaporative coolers can be shipped with factory-mounted controls that will cycle the fan and pump On/Off as needed to maintain the desired temperature set point based on the geographic location where it will be used. The system may still require some field adjustments. The outlet plumbing from the cooling tower will have two temperature sensing bulbs installed to control the outlet temperature of the tower. One bulb will be set to turn on the spray pump about 10°F below the required equipment inlet water temperature. The second bulb is set to turn on the blower motor about 5°F below the required equipment inlet temperature. The blower will then remain on until the water drops to a temperature less than 5°F below the required equipment inlet temperature. The spray pump will stay on until the water temperature drops to 10° F below the required equipment inlet water temperature.

In a closed-circuit pressurized tower, a thermostatically controlled electric heater in the spray water sump pan turns on at a temperature of approximately 40°F to prevent freeze up in cold weather (Figs. 6 and 7). A float-operated valve controls the sump water level. These systems should have bleed-off controls to add enough water to overflow and allow scale and calcium to escape the tank.

Open Evaporative Cooling Towers

The use of a heater or glycol is not required with open evaporative tower having a gravity-drained sump tank mounted just inside the heated building. These systems have the tower mounted high on a platform outdoors (Figs. 8 and 9). An open tower usually costs less, but it requires extensive cleaning, good filtering for leaves, feathers, and other debris that is drawn into the tower. There is no cooling bundle, just a cascade of water down a series of fins which gravity drains inside the building.

Reducing the risk of Legionella bacteria can be accomplished by thorough cleaning on a regular basis. If a tower is to be idle for an extended time, it should be completely drained. If draining is not practical, a chemical shock with a biocide may be required to kill the bacteria.

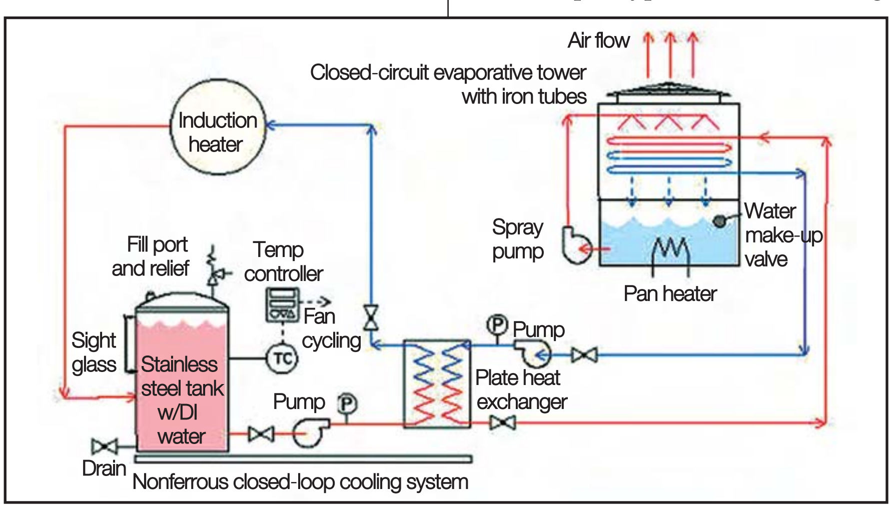

Fig. 7 — Schematic of a closed-loop pressurized evaporative cooling tower. Courtesy Dry Coolers Inc., Oxford, Mich.

Fig. 8 — Open evaporative cooling tower with gravity drain to holding tank indoors.

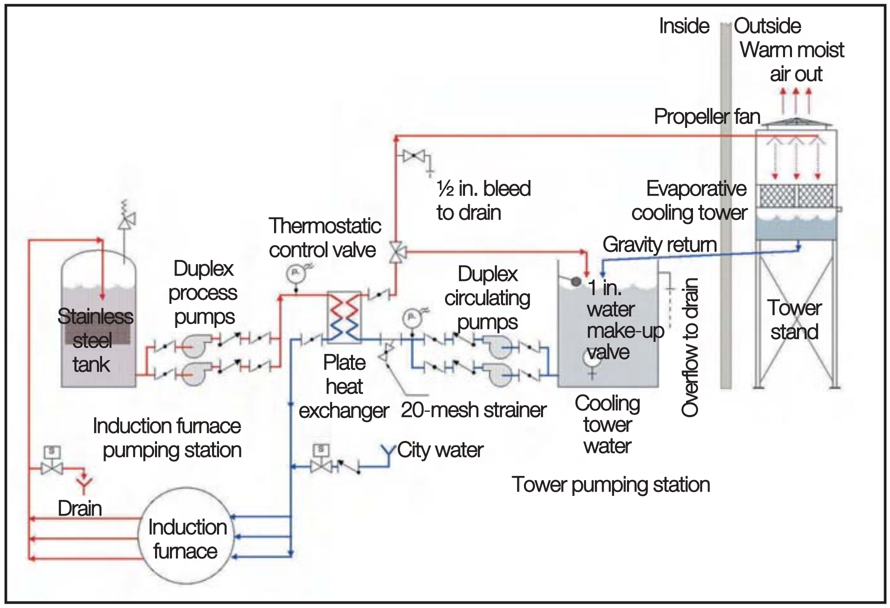

Fig. 9 — Schematic of open evaporative tower with emergency city water option. Courtesy Dry Coolers Inc., Oxford, Mich.

Fig. 10 — Multiple cooling tower installation; one tower for each induction system.

Fig. 11 — Avoid chain link fences with aesthetic inserts (reduces fresh airflow) and locations next to gravel parking lots.

Individual cooling tower are best for multiple induction systems (over 500 kW), which eliminates the possibility of a breakdown of more than one induction system if a tower or pump has failed (Fig. 10). Smaller towers are easier to clean than a single large tower. This is solely an economic decision, because multiple small towers cost more to install and take up more real estate, but potential downtime concerns and cleaning cost need to impact that decision.

Placement of Cooling Towers

Avoid placing any outdoor tower near gravel or dirt parking lots and sand blast or shot-reclamation systems, which could produce dust that is sucked into the tower, requiring additional maintenance and reducing its efficiency (Fig. 11). Positioning of the cooling tower is of the utmost importance to reduce the chances of air recirculation, which occurs when some of the moist, hot exhaust air leaving the tower is drawn back in the fresh intake vent. Placement and position related to the prevailing wind in the summer for the particular geographic area and distance and height related to any buildings can all cause recirculation (Figs. 12 to 14).

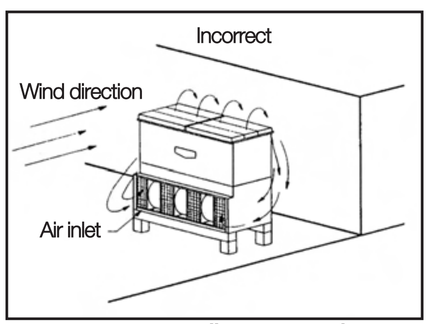

Fig. 12 — Incorrect installation position due to prevailing wind causes recirculation of moist air. Courtesy EVAPCO Inc., Taneytown, Md.

Avoid placing hurricane fencing or chain link fence with aesthetic inserts, as they will restrict fresh air intake and cause recirculation of moist hot air (Fig. 15). The heat-laden exhaust air is saturated and can be at a 10 to 15°F higher wet-bulb temperature than the ambient wet bulb. The cooling capacity of the unit is drastically reduced when recirculation occurs.

Indoor installations of evaporative

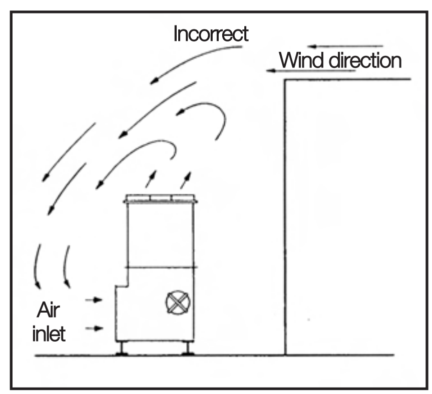

Fig. 13 — Incorrect installation position related to height of the building and prevailing wind direction. Courtesy EVAPCO Inc., Taneytown, Md.

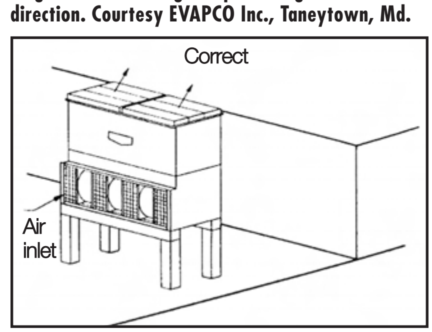

Fig. 14 — Correct installation position related to height of the building. Courtesy EVAPCO Inc., Taneytown, Md.

Fig. 15 — Gang of cooling towers placed too close together with no regard to fresh air intake.

Fig. 16 — Out-door view of indoor closed-loop evaporative towers with fresh air inlet openings at bottom and exhaust out just below the roofline. Roof mounted exhausts fans at this Minnesota foundry supply extra plant ventilation to reduce the humidity inside the plant.

Fig. 17 — Refrigeration chiller with filter panels removed used to direct cool an induction power supply.

cooling towers are commonly used in extreme northern locations where temperatures can reach -40 to -50°F (Fig. 16). Canvas drapes (not shown) are hung on the exterior wall in winter to the exhaust side to prevent cold-air back drafts into the plant. The biggest advantages are to prevent freezing and frost build up of the tower, and supplemental heat that can be used to heat the plant. Inside installations of cooling towers require larger motors with more horsepower due to the increased backpressure of the venting ductwork. Placement of the fresh air intake and exhaust are critical to prevent recirculation of moist laden air.

Refrigerant Chillers

Refrigerant chillers cool by mechanical-refrigeration principals. Air- or water-cooled condensers are available with non ozone-depleting refrigerant (Fig. 17). These systems are predominantly used on small induction systems less than 200 kW. They can be open or closed-looped with an integral evaporator or secondary heat exchanger. These systems are the most expensive, and have high operating costs, but very low maintenance. They usually are indoors and discharge hot air into the plant, which can supplement plant heating.

The advantage of a chiller is they are compact and can take the place of the water-to-water heat exchanger, pump, and controls shown in Fig. 1. A closed-loop quench system with its own heat exchanger is still needed to control the quench system temperature. Chiller recirculating temperature can be set at 85°F, which eliminates condensation in the power supply.

The following is an example of the cooling water specification for a refrigeration chiller with nonferrous cooling bundle and holding tank used to directly cool induction power supplies.

Total hardness ($CaCO_3$)	15 ppm
Total dissolved solids	25 ppm
Conductivity	20 to 70 μmho/cm
Max suspended solids	10 ppm
pH	7.0 to 7.5

Fig. 18 — Geothermal cooling field, using plastic 2.5-in pipe shown in foreground.

Geothermal

Underground cooling systems work very well when less than 300 kW needs to be dissipated. Over this kW rating, the size of the field is considered too large. The ground is at a constant 55° F ambient temperature below the freeze line. A geothermal system consists of a pump, heat exchanger, expansion tank, inlet valve, controls, and air bleed vents at the highest points of the plumbing. The water temperature sensor that was used to open the solenoid to the heat exchangers now is used to turn on the pump, and the solenoid is eliminated to allow a free flow of water. A mixture of 30% glycol is still recommended to buffer the water.

The underground plumbing usually contains dual parallel loops that consist of special geothermal poly/plastic materials and glued fittings. One pipe run is buried at about 5 ft and the other at 7 ft, about two linear feet apart. These depths depend on the freeze line at the particular geographic location. In Florida, a 2 to 4 ft depth is adequate, while a 6 to 8 ft depth is required in Canada. The geothermal installation shown in Fig. 18 is located in central Michigan and has been in service for over ten years.

Summary

Many factors can affect performance of water-cooling systems used for induction heating systems. Poor maintenance can cause the long-term reliability of the induction system to be reduced. The cooling tower placement related to prevailing winds and surrounding buildings can affect its performance, and cost of operation.

Water-cooling circuits are the most neglected item in induction maintenance, causing the most down time and damage. The damage caused is insidious as the damage being done cannot be seen. The system operates until partial plugging of a water path occurs, and expensive devise failure follows. These SCR, diode, and transformer failures can cost thousands of dollars, but to the untrained eye cannot be directly linked back to the high conductivity of the water.

Common-sense installation and maintenance practices can help reduce unexpected down time, thereby increasing profits for the user. New and improved hybrid systems are being used in various combinations to reduce costs. Great success in cooling the induction heating system at a low cost over decades of service even on the hottest days can be achieved if these simple rules are implemented. **HTP**

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