White Paper

When You Need Humidity – Every Drop Counts

condair

Introduction

The purpose of this document is to explain how Nortec Electrode Steam Humidifiers condition the indoor environment while making the most efficient use of water. The electrode steam humidifier's water use is compared to that of resistive steam, gas-fired and steam-exchange technologies.

Patented in the 1890's, the electrode principle was one of the first technologies developed to use electricity to heat water. Electricity is passed through the water between immersed electrodes to generate heat and steam.

This 120-year-old technology has been optimized for the 21st century with Nortec's patented Auto-Adaptive Control algorithm. With this control, Nortec Electrode Steam Humidifiers (Figures 1, 2, & 3) optimize water management. The benefits include reduced water use, extended electrode life and reduced maintenance.

Figure 1: Commercial Electrode Humidifier – Nortec NHTC/NHPC

Figure 2: Residential Electrode Humidifier – Nortec RH2

Figure 3: OEM Electrode Humidifier – Nortec MES2

Isothermal Humidification and Water Use

During the isothermal humidification process, humidity is increased at constant temperature. This may only be achieved by introducing steam into the air. Thus, the humidifier's function is to boil water and to distribute the steam into the conditioned space. An external heat source is required and humidifiers may be classified by the energy source and heating mechanism (Table 1).

Table 1: Isothermal Humidifier Types and Heating Mechanisms

Isothermal Humidifiers Types	Energy Source	Heating Mechanism
Electrode	Electricity	Electrical resistance of water
Resistive heating	Electricity	Resistive element
Gas-fired	Natural gas or propane	Air-to-water heat-exchanger
Steam-exchange	Boiler steam	Air-to-water heat-exchanger

Each isothermal technology presents its own challenge for efficient water use. Water is known as the universal solvent. Minerals are dissolved from the geological location containing the water. The concentration of dissolved minerals is defined by the TDS (total dissolved solids) concentration. Many of these dissolved impurities and minerals can harm a humidifier.

Steam produced by humidifiers is de-mineralized. As pure water boils off, dissolved and precipitated minerals in the initial water volume are left behind in the reservoir. The corrosiveness of the remaining water increases as the impurities become more concentrated. The primary method for humidifiers to limit high concentrations is to drain the reservoir on a regular basis and then replenish with fresh water. Typically, drains are frequent but small in volume, ensuring steam is always available for humidification. But the concentration of contaminants will continue to increase over time and the reservoir must be drained completely at regular intervals during the operating period.

An important factor for humidifier operation is water hardness, measured by the concentration of dissolved calcium carbonate ($CaCO_3$). Calcium carbonate's solubility decreases as water temperature increases. Consequently, as water is heated, calcium carbonate precipitates out of solution and forms scale. The scale sinks to the bottom of the humidifier's reservoir and is deposited on the electrodes, heat-exchangers and heating elements. Scale is not a good conductor of heat so it reduces heat-transfer efficiency and increases failure rates. Frequent maintenance is required to remove scale build-up.

Other harmful conditions occur when the supply water is acidic (low pH) and/or has a high chloride (Cl-) level. Unlike calcium carbonate, the solubility of chlorides increases with water temperature. When allowed to over-concentrate, acidic or high-chloride water can deteriorate metal components.

Water conditions vary considerably with installation location. To ensure consistent humidifier operation, manufacturers set a conservative regimen of drain volumes and durations. The end-user may fine-tune drain times and schedules based on maintenance observations and water quality.

Electrode Steam Humidification

How do electrode steam humidifiers work?

Potable water contains many dissolved impurities. These impurities are actually required for the production of steam in electrode humidifiers. Pure water is essentially an insulator, but the

dissolved salt and mineral ions in this electrolyte solution allow for electricity to be conducted between the submerged electrodes. Heat is generated by the resistance of the water to the current flow: the water actually becomes the heating element. The Nortec cylinder is the heart of the Nortec electrode humidifier (figure 4).

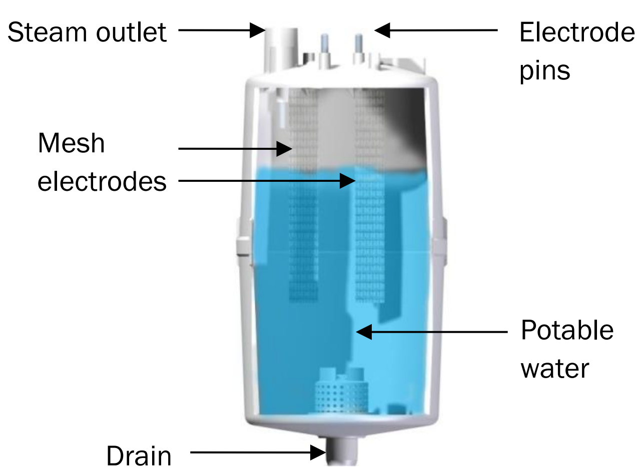

Figure 4: Nortec Cylinder

The relationship between voltage, current and resistance is defined by Ohm's law:

$$\text{Current (A)} = \frac{\text{Voltage (V)}}{\text{Resistance }(\Omega)}$$

Current is measured in amperes or amps (A), voltage is measured in volts (V), and resistance is measured in ohms (Ω).

Given that an increase in the concentration of salt and mineral ions increases water's conductance, it is practical to use conductance instead of resistance for describing steam output of an electrode humidifier. Conductance, measured in Siemens (S), is defined as the reciprocal of resistance. (It is also sometimes measure in mhos, the "inverse" of ohms.)

$$\text{Conductance (S)} = \frac{1}{\text{Resistance }(\Omega)}$$

At constant voltage, the current varies proportionally to conductance. In other words, as the concentration of ions increases and the conductance goes up, the current increases.

$$\therefore \text{Current (A)} = \text{Voltage (V)} \times \text{Conductance (S)}$$

The power output is proportional to the current carried by the water: increasing the current results in increased steam output. Electrical power is typically expressed in *kW*. If we consider that electrical energy is converted to heat, we can express the power output in *btu/hr*. As the steam produced is at atmospheric pressure, the energy per unit of steam is fixed so the power output may also be expressed by the amount of steam produced in *lb/hr*.

$$\text{Power/steam output} \propto \text{Voltage (V)} \times \text{Current (A)}$$

It would appear to be a straightforward relationship such that if more steam was required, the current could simply be increased. But the humidifier's controller must manage what is, in fact, a much more complex relationship.

The wetted surface area of the electrodes changes throughout the regular draining and filling stages. During a drain cycle, as less and less of the electrode surface area is in contact with the electrolyte (water with dissolved ions), the current will drop. During filling, as more of the electrode surface area comes in contact with the electrolyte, the current will increase. As steam is still being generated throughout this process, the concentration of ions continues to fluctuate.

Not only are there variations in water level and concentration, the demand for humidity in the conditioned space also fluctuates. Maintaining constant steam output for effective and accurate humidification requires constant vigilance and continuous adjustment.

A precise water management algorithm is critical. Nortec's patented Auto-Adaptive Control algorithm (Figure 5) ensures that steam output follows the humidity demand even as the water level and conductance fluctuate. The humidifier controller calculates steam output from the measured current draw.

Periodic drains are required to maintain conductivity within the operational range. Drain times are calculated by comparing the current's measured rate of change (T_M) to a constant (T_O). Derived from 35 years of experimental testing, this constant is the optimal time (T_O) to perform one boil down cycle. One boil down cycle starts when the cylinder is filled (fill on amps) and ends when filling stops (fill off amps). If the current/time derivative is less than optimal, the humidifier fills to restart the boil cycle. If the current/time derivative exceeds the constant, the controller calculates a drain time (T_D) by differentiation of the current's rate of change.

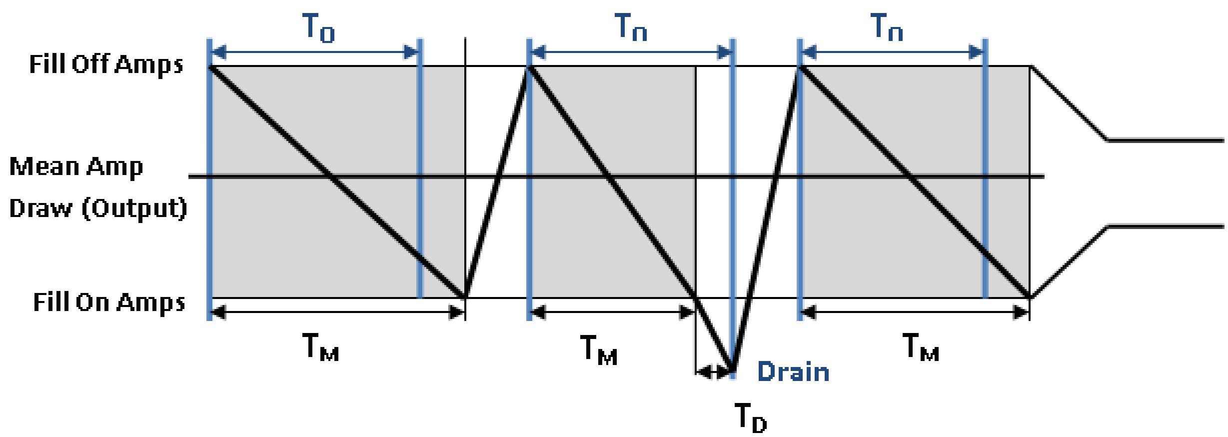

Figure 5: Auto-Adaptive Control Algorithm

Humidifier Water Consumption

How much water does a Nortec humidifier consume?

Let's take a look at a humidifier's water consumption during one year. For this example, the humidifier output is 100 pounds of steam per hour. The average humidification season lasts from late September to late April, with roughly 2,000 hours of humidifier operation. Humidifiers usually operate during winter months as indoor relative humidity levels drop significantly during heating. Total steam produced during this period is:

$$100 \ \mathrm{lb/hr} \times 2000 \ \mathrm{hr} = 200{,}000 \ \mathrm{lb}$$

Each pound of steam requires one pound of water. Assuming a density 0.12 US gal/lb, the water required is:

$$200{,}000 \ \mathrm{lb} \times 0.12 \ (\mathrm{US\ gal})/\mathrm{lb} = 24{,}000 \ \mathrm{US\ gal}$$

This is the minimum amount of water required to produce 100 lbs/hr for 2,000 hours with any technology.

How much water is drained during this period?

The amount drained depends on the technology: Electrode Steam, Resistive Steam, Gas-fired or Steam-exchange; and whether potable water or treated water is used (de-mineralized or reverse osmosis water).

Electrode Humidification Water Consumption

The most important consideration in electrode humidification is the conductance between the electrodes. The ability of the electrolyte to conduct electricity is measured by its specific conductance, or conductivity, measured in *microSiemens* per centimeter (*µS/cm*). It is measured by determining the conductance (or resistance) of a fluid between two points at a fixed distance.

Essentially, the higher the water supply's conductivity, the greater the concentration of ions. Using water with a high conductivity, a humidifier will require a high drain rate, using more water to maintain optimum conductance. Water with a low conductivity will permit a reduced drain rate. The Nortec Auto-Adaptive Controller effectively manages this process by monitoring current draw and conductivity and adjusting drain cycles to minimize water use.

Returning to the 100-lb/hr example, let's assume that the humidifier is a Nortec Electrode Steam Humidifier operating at constant steam output. The drain rate will thus be entirely dependent on supply-water conductivity. Water conductivity varies throughout North America so the actual drain rate is dependent on installation location.

The average conductivity of major US [1] and Canadian [2] potable water sources is 300 µS/cm. See Table 7(Appendix) for conductivities of major US water sources. From figure 6 (Appendix), the drain rate for water this conductivity is 24%.

Therefore, a 100-lb/hr Nortec Electrode Humidifier operating at maximum output for 2,000 hours with supply water of average conductivity will drain:

$$24\% \times 24{,}000 \text{ US Gal} = 5{,}760 \text{ US gal}$$

A major advantage of Nortec Electrode Humidifiers is that there is no requirement to completely drain the tank. It is only necessary to drain sufficient water to maintain the reservoir's conductivity,

Table 2: Water Efficiency of an Electrode Steam Humidifier

Technology	Water consumption for humidification (US gal)	Drain water volume (US gal)	Total water consumption (US gal)	Water Efficiency
Electrode Steam with Potable Water	24,000	5,760	29,760	81%

Resistive Element Humidification Water Consumption

Resistive element humidifiers also use electricity to generate steam. But instead of passing electrical current through water, current flows through a submerged heating element. Heat is generated in the resistive element and transferred directly to the water. There is no dependence between steam production and water conductivity.

The steam produced is always pure or de-mineralized, leaving impurities to concentrate in the reservoir. It is important to manage the calcium carbonate concentration as well as pH and chloride levels to protect wetted components. Scale is deposited on to the hot heating elements reducing efficiency and increasing failure rates. Low pH and high chloride levels will lead to deterioration of metal components. Regular drain cycles are required to reduce scale build-up and to limit corrosion.

From experimental testing, the typical drain rate of a resistive element humidifier is 36% of the steam output. A 100-lb/hr resistive element humidifier consumes 24,000 US gal of water for humidification. An additional 36%, or 8,640 US gal, of this water volume is used in drain cycles:

$$36\% \times 24{,}000 \text{ US gal} = 8{,}640 \text{ US gal}$$

A complete flushing of the reservoir must be completely on a regular basis to remove scale build-up. In this example, the reservoir must be flushed after 25,000 pounds of steam generation.

As the 100-lb/hr humidifier produces 200,000 pounds of steam in a season, its 20 US gal reservoir must be drained four times (adding an additional drain volume of 160 US gal).

Table 3: Water Efficiency of Resisitve and Electrode Steam Humidifiers

Technology	Water consumption for humidification (US gal)	Drain water volume (US gal)	Total water consumption (US gal)	Water Efficiency
Electrode Steam with Potable Water	24,000	5,760	29,760	81%
Resistive Steam with Potable Water	**24,000**	**8,800**	**32,800**	**73%**

Heat-Exchanger Humidifier Water Consumption

There are two humidifier technologies within this group: steam-exchange and gas-fired. Both make use of a heat-exchanger for producing steam. A gas-fired steam humidifier uses the combustion of natural gas or propane for heat generation. A steam-exchange humidifier uses pressurized steam from a facility boiler system as a source of heat to generate steam from a potable water supply.

These humidifiers must also drain periodically to prevent excessive scaling of the heat-exchanger(s) and reservoir, and to prevent blockage of the drain port(s). The steam produced in these humidifiers is also mineral-free, and so impurities concentrate in the reservoir. Frequent draining is critical to reduce maintenance and to prolong the life of wetted components.

A sump port or drain pump is typically used for gravity or mechanical draining. The drain rate is normally set at 25% of total steam output [3]. The humidifier will also completely flush the reservoir at regular intervals [3].

A 100-lb/hr gas or steam-exchange humidifier will consume 24,000 US gal of water for humidification. An additional 25%, or 6,000 US gal, of this water volume is used in drain cycles:

$$25\% \times 24{,}000 \text{ US Gal} = 6{,}000 \text{ US Gal}$$

The 20-US gal reservoir also undergoes a complete drain after every 72 hours of weighed steam output (about 28 flushes over the humidification season). An additional 560 US gal of water is used for flushing the reservoir.

Table 4: Water Efficiency of Gas-Fired, Steam-Exchange, Resistive, and Electrode Steam Humidifiers

Technology	Water consumption for humidification (US gal)	Drain water volume (US gal)	Total water consumption (US gal)	Water Efficiency
Electrode Steam with Potable Water	24,000	5,760	29,760	81%
Resistive Steam with Potable Water	24,000	8,760	32,760	73%
Gas-fired and Steam-exchange with Potable Water	**24,000**	**7,500**	**30,560**	**78.5%**

Treated Water – Reverse Osmosis Humidifier Water Consumption

Resistive element, gas-fired and steam-exchange humidifiers do not rely on dissolved ions in the water to generate steam. Using very pure or de-mineralized water can significantly reduce the required drain rates and cleaning frequency. Given that electrode humidification relies on dissolved salt and mineral ions to pass current for steam production, it is not possible to produce steam from de-mineralized water in electrode humidifiers.

While water treatment is advantageous for humidifier water efficiency, it is necessary to consider the water treatment system's efficiency. During the reverse osmosis (RO) process, only a certain amount of water permeates through the membrane for use as clean water. The remaining water is a concentrate of impurities and is removed. The concentrate may even need to be diluted for safe disposal. Excess water is used to flush and to remove mineral build-up from the membrane.

The drain rate of a reverse osmosis water treatment system may be defined by the recovery rate. The typical recovery rate of a reverse osmosis system is 75%, meaning 25% is lost [4]. As the water has a very low hardness, the humidifier drain rate may be reduced to 10% of total output. Drains are still necessary to maintain proper pH levels and to protect metal components. Even though the supply-water hardness is very low, there are still some constituents that can damage the humidifier if allowed to over-concentrate.

A 100-lb/hr resistive element, gas-fired or steam-exchange humidifier consumes 24,000 US gal water for humidification. The total drain rate is the sum of the reverse osmosis losses and of the humidifier drain cycles. Fortunately, there is no need to completely empty the reservoir during the period of operation.

$$25\% \times 24{,}000 \text{ US gal} = 6{,}000 \text{ US gal}$$

$$10\% \times 24{,}000 \text{ US gal} = 2{,}400 \text{ US gal}$$

Table 5: Water Efficiency of Heat-Exchange, Resistive, and Electrode Humidifiers with Potable or RO Water

Technology	Water consumption for humidification (US gal)	Drain water volume (US gal)	Total water consumption (US gal)	Water Efficiency
Electrode Steam with Potable Water	24,000	5,760	29,760	81%
Resistive Steam with Potable Water	24,000	8,760	32,760	73%
Gas-fired and Steam-exchange with Potable Water	24,000	7,500	30,560	78.5%
Resistive, Gas-fired and Steam-exchange with RO Water	**24,000**	**8,400**	**32,400**	**74%**

Energy Savings

Not only do efficient drain rates economize water, they also reduce the energy input. Each pound of water sent to drain is wasted heat. A BTU is the energy required to heat one pound of water by one degree Fahrenheit. Assuming the water to be boiled is initially at 60°F, heating one pound of water from 60°F to 212°F requires 152 BTUs of energy. Each pound of water sent to drain removes 152 BTUs of energy from the system. Assuming a density of 8.00 lbs/US gal (212°F), every 10 gallons of water removes 12,160 BTUs or 3.6 kWh from the system.

Using $0.10 per kWh [5], the electrical cost of draining 10 US gallon of water is:

$$3.6\ \text{kWh} \times \frac{\$0.12}{\text{kWh}} = \$0.43$$

Using $10 per 1000 cubic feet [6], the natural gas cost of draining 10 US gallon of water is:

$$\frac{12{,}160\ \text{BTU}}{1{,}000{,}000\ \frac{\text{BTU}}{1000\ \text{ft}^3}} \times \frac{\$10.00}{1000\ \text{ft}^3} = \$0.12$$

Returning to the 100-lbs/hr example, it is possible to calculate the annual cost of wasted energy.

Table 6: Annual Cost of Wasted Energy from Humidifier Draining Volumes

Technology	Drain water volume (US gal)	Wasted Energy Cost (USD)
Electrode Steam with Potable Water	5,760	$248
Resistive Steam with Potable Water	8,760	$377
Gas-fired and Steam-exchange with Potable Water	7,500	$90
Resistive Steam with RO Water	*2,400	$103
Gas-fired and Steam-exchange with RO Water	*2,400	$29

*Note: water efficiency of the humidifier only. RO system water efficiency is not considered for humidifier energy cost calculation.

Conclusion

Additional inefficiencies and water losses occur in the steam distribution system. It is important to address these to ensure the highest overall water efficiency is achieved. The steam line must be insulated to minimize condensate losses while the steam travels to the distributor. Nortec recommends wherever possible to use the SAM-e insulated short absorption manifold distributor to minimize condensate losses. The SAM-e distributes steam uniformly into the air stream. The insulation of the SAM-e reduces condensate losses by up to 70%, while ensuring efficient and hygienic operation.

To ensure that a humidifier performs effectively and robustly under varying conditions, drain cycles must be implemented. The patented Nortec Auto-Adaptive Controller optimizes drain rates to match incoming water conditions. Regardless of the water conditions, a Nortec electrode humidifier will automatically maximize water and energy efficiencies. When you need humidity and every drop counts, choose Nortec Electrode Steam.

Appendix

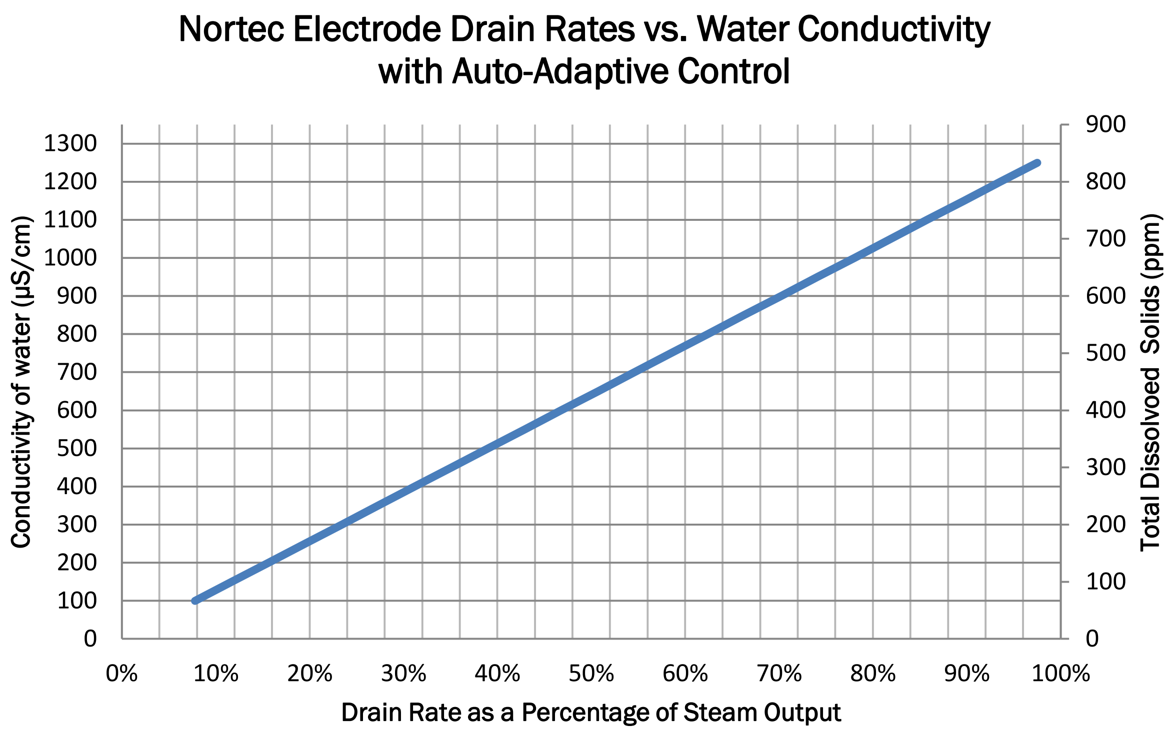

Figure 6: Nortec Electrode Drain Rates
(Conversion Factor of 0.08% per µS/cm)

Table 7: Selected Water Analyses for Major US Water Sources [1]

Water Source	Total Dissolved Solids (mg/L)	*Conductivity (µS/cm)
Selected rivers		
Delaware at Morrisville, PA	84	130
Edisto at Charleston, SC	46	71
Chattahoochee at Atlanta, GA	33	51
Ohio at Steubenville, Ohio	143	222
Tenesse at Decartur, AL	113	175
Mississippi at St-Louis, MO	326	505
Missouri at Great Fall, MT	234	363
Missouri at Kansas City	365	566
Neche at Evadale, TX	96	149
Colorado as delivered to Los Angeles, CA	661	1025
Columbia at Wenatchee, WA	100	155
Scaramento at Sacramento, CA	36	56
Watersheds supplied by precipitation		
Greenville, SC	17	26
New York City (Catskill), NY	34	53
Boston, MA	33	51
Frederick, MD	12	19
Little Rock, AR	25	39
Colorado Springs, CO	33	51
Selected lakes		
Lake Superior at Duluth	54	84
Lake Michigan at Chicago	171	265
Lake Erie at Erie, PA	172	267
Seneca Lake, Geneva, New York	323	501
Lake Coeur d'Alene, Idaho	58	90
Clear Lake, West Palm Beach, FL	173	268
Selected wells		
Manhattan, Kansas	488	756
Amarillo, Texas, Well No. 1	530	822
Baytown, Texas, Well No. 1	733	1136
Phoenix, Arizona	887	1375
Norman, Oklahoma	550	853
Richland, Washington	307	476
Cambden, NJ, Well No. 1	181	281
Cambden, NJ, Well No. 7	103	160
Cambden, NJ, Well No. 9N	118	183
Ft. Lauderdale, FL	314	487
Bastrop, LA	697	1080
Dallas, TX, Well No. 39	1040	1612

* Conversion factor is 1.55 µS/cm per milligram/liter [1]

References

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[5] "*Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State*", Table, U.S. Energy Information Administration, 15 Nov 2010.
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[6] "*Natural Gas Price*", Table, U.S. Energy Information Administration, 29 Nov 2010.
eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm

Why Condair?

Condair specializes in the design and production of superior humidification systems. We create the most appropriate solutions to meet your specific needs in the most efficient and cost effective way. To this end, we draw upon our extensive experience to develop an ever growing range of products manufactured to our stringent ISO 9001:2000 certified quality standards that will provide our customers with maximum reliability, minimum maintenance and a choice of energy sources.

When you choose Nortec Humidity, you are choosing the company that has built a reputation for superior quality humidification systems. Only with Condair can you select a system operating with electrode steam, subsonic air nozzles, high pressure nozzles, steam injection, steam exchange, or gas-fired technology.

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