



Chapter 1

History of Chlorination and Chloramination

Chlorine was “discovered” in 1744 in an obscure laboratory in Sweden (AWWA 1973). Sixty-six years later in 1810, chlorine was identified as a chemical element and was named from the Greek word *chloros* (pale green), because of its characteristic color. However, it was not until several decades later that its use as a disinfectant was recognized.

Until the germ theory of disease was established around the mid-1880s, odors were thought to be responsible for transmitting diseases. As such, it was widely believed that the control of odors would limit the spread of infections. There is no question that the earliest applications of chlorine were aimed at controlling foul odors (Baylis 1935), even though, because of the unsophisticated techniques used, the chlorinous odor imparted to the treated water was sometimes just as, or more, objectionable than the odor it was meant to remove. It was not until well into the 1890s that chlorine and chlorine-containing products were evaluated and demonstrated to be effective disinfectants.

ORIGIN OF WATER DISINFECTION

Undoubtedly the disinfection of water has been practiced for millenniums, although probably with little or no understanding of the principles involved. Historical records indicate that the boiling of water had been recommended at least as early as 500 B.C. The earliest recorded use of chlorine directly for water disinfection was on an experimental basis, in connection with filtration studies in Louisville, Ky., in 1896. It was employed for a short period in 1897 in England, again on an experimental basis, to sterilize water distribution mains following a typhoid epidemic.

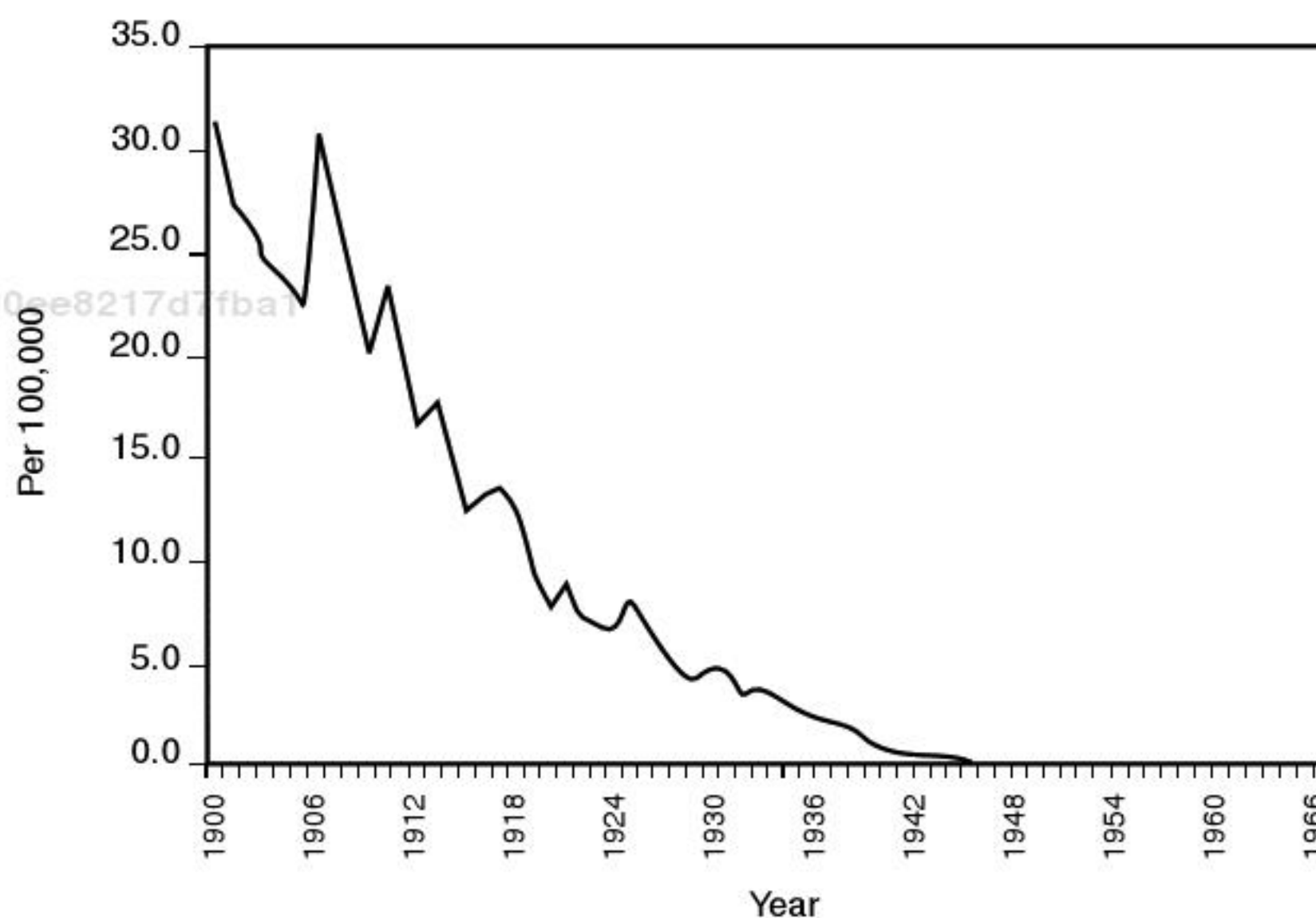
The first *continuous* use of chlorine for water disinfection was in 1902 in Belgium for the dual objective of aiding coagulation and making water biologically “safe.” In North America, the first continuous, municipal application of chlorine to water was in 1908 to disinfect the 40-mgd (151-ML/d) Boonton Reservoir supply of the Jersey City, N.J., water utility. Contested in the courts, the practice was declared to represent a public health safeguard, and this action paved the way for its rapid extension to other public water supplies throughout North America and elsewhere.

RATIONALE OF WATER DISINFECTION

Waterborne diseases, such as typhoid, dysentery, and cholera, occurred with regularity in US water systems in the 1800s. The incidence rates were high in the early 1900s (e.g., more than 25,000 typhoid deaths in 1900) but decreased rapidly with the onset of chlorination (e.g., less than 20 deaths in 1960) (Laubusch 1964), as shown in Figure 1-1. The data provide similar results for other organisms.

With such a dramatic drop in illnesses and fatalities following the onset of chlorination, the need for feeding these chemicals was well justified. To date, chlorine has emerged as the disinfectant of choice primarily because of its effectiveness (Race 1918), efficiency, economy of operation, convenience, and the persistence of a chlorine residual. The unique properties of chlorine also make its use an acceptable technique for taste-and-odor control, algae and slime control, water-main disinfection, and many other purposes. However, chlorine has come under intense scrutiny because some of the by-products of the disinfection process may be carcinogenic. In spite of this, chlorine is expected to remain in wide use.

Water disinfection, as now ordinarily considered, involves specialized treatment for the destruction of harmful, and otherwise objectionable, “nuisance” organisms. Classically, disinfection processes have been employed to destroy or inactivate disease-producing (pathogenic) organisms—more particularly bacteria of intestinal origin. Such organisms can survive for weeks in the environment at temperatures near 70°F (21°C), or possibly even for months at lower temperatures. In addition to temperature influences, their survival in water depends on environmental, physiological, and morphological factors, such as pH, oxygen and nutrient supply, dilution, competition with other organisms, resistance to toxic influences, and ability to form spores. Whether these organisms actually will cause disease in humans upon ingestion depends on their virulence and concentration and also on the individual’s vulnerability or susceptibility to them.



*Based on Vital Statistics of the United States 1937, 1938, 1943, 1944, 1949, 1960, 1967, 1976, 1987, 1992, Historical Statistics of the United States—Colonial Times to 1970 Part 1.

Source: HealthSentinel.com.

Figure 1-1 US typhoid mortality and disease rates

Water disinfection also encompasses the destruction of disease-producing organisms other than intestinal bacteria, but it does not necessarily imply the complete destruction of *all* living organisms (i.e., *sterilization*). Water disinfection processes seldom have been carried to the point of sterilization, which has been largely confined to the medical field. Among the other disease-producing organisms important in regard to water disinfection are a variety of viruses, intestinal protozoa, and some macroorganisms. In addition, many nuisance organisms of aesthetic or economic significance, both plant and animal, are sometimes vulnerable to disinfection and can be partially or completely controlled by suitable treatment.

EVOLUTION OF CHLORINATION MATERIALS

During the infancy of water chlorination, the only commercial sources of chlorine were dry chlorine-containing *compounds*, such as chlorinated lime (also called chloride of lime and bleaching powder) and sodium hypochlorite bleach solutions. The poor stability and variable effective chlorine content of the compounds then available caused many operating difficulties, and often inadequate disinfection dosages were used. Moreover, the comparatively crude equipment feeders yielded erratic results.

In 1909, liquid chlorine (the element in compressed form) became available commercially, and in the following year it was employed experimentally for water disinfection in Fort Myer, Va. The chlorine was added to the water by using a simple dry-gas feeder. In 1912, the first full-scale successful use of liquid chlorine was undertaken to control a recurring outbreak of typhoid in Niagara Falls, N.Y. In this case, a solution feeder was used. Two years later, improved equipment developed by C.F. Wallace and M.F. Tiernan to measure chlorine gas, dissolve it in water, and apply the solution was installed in Boonton, N.J., replacing the use of sodium hypochlorite bleach. These developments paved the way for the future extension of water disinfection techniques utilizing liquid chlorine.

Hypochlorite water chlorination gradually decreased in popularity, but it received renewed interest in 1928 with the commercial availability of high-test calcium hypochlorite, which was a more stable and active material than the various bleaching powders and solutions previously available. Today, there are three principal sources of chlorine for water disinfection and other chlorination treatment: (1) in elemental form, as a liquefied compressed gas (in commerce); (2) as "high-test calcium hypochlorite"; and (3) as chlorine bleach solutions (not to be confused with elemental liquid chlorine or with water solutions of chlorine gas).

EVOLUTION OF CHLORINATION CONTROL PRACTICES

Improvements in chlorine disinfection materials and in chemical feeders substantially contributed to the popularity and widespread adoption of water chlorination. Originally disinfection dosages were based largely on the application of fixed amounts of chlorine. Soon it became apparent that provisions were not being made for the effects of variations in water quality and the fluctuation in chlorine demand.

Gradually, the concept of varying chlorine dosage on the basis of residual chlorine was established, and iodometric methods for qualitative and quantitative assay of residual chlorine were developed. The use of orthotolidine as a qualitative indicator of residual chlorine was proposed in 1909, and later its use was extended quantitatively by the development of colorimetric standards. Between 1917 and 1919, chlorine disinfection was established on a scientific basis when the suitability and reliability of the orthotolidine test for even the smallest water supplies were demonstrated. Since then, a better understanding of water chlorination processes has brought many refinements in that test and in the development of other tests, such as the orthotolidine-arsenite colorimetric test to distinguish forms of residual chlorine, amperometric differential

titration, and various other differential chemical tests for available chlorine. In recent years, the use of orthotolidine reagent has been discontinued in favor of the safer and more stable *N,N*-diethyl-*p*-phenylenediamine (DPD) method. DPD is commonly used both for color comparison and titrimetric chlorine testing.

DISCOVERY OF TRIHALOMETHANES

As chlorination processes gained further acceptance, new discoveries were limited to refinements in the existing methods and chemistry (Connell 1996). It wasn't until the 1970s that trace organic chlorination by-products were discovered. In Holland, Rook identified that the reaction of chlorine with organic materials dissolved in water produced a class of compounds called trihalomethanes (THMs) (Connell 1996). The organics, usually humic and fulvic acids that originate in decaying vegetative growths, can be found in agricultural runoffs, aquifers, and natural vegetation.

The THMs were identified as possible cancer-causing agents, and their discovery in drinking water raised concerns about chlorination. Research began on the nature of the reactions that produce THMs, the concentrations of THMs considered unacceptable in drinking water, and methods to reduce or prevent their formation. The great rush of scientific work produced sufficient data to lead regulatory bodies in Europe and North America to set acceptable THM concentration levels in finished water and to determine ways to minimize THM formation in existing plants.

HISTORICAL DEVELOPMENT OF CHLORAMINE

It is likely that chloramines formed accidentally in wastewater and in waters containing natural ammonia for some time before this reaction was characterized. In the early 1900s, the chlorine-ammonia combination received attention when it was found that the cost of chlorination might be reduced if ammonia was added (Race 1918). The practice of chloramine treatment was adopted in 1916 at the treatment plant in Ottawa, Ont. The first installation in the United States was in 1917 in Denver, Colo. Both locations used ammonia and hypochlorite and noted improvements in taste and reductions in after-growth in the distribution system.

Additional utilities adopted the use of chlorine-ammonia in the years that followed, as listed in Table 1-1, and more than 400 utilities were using the process by 1938. Breakpoint chlorination was discovered in 1939, and thereafter, the use of chloramines declined. Chloramine usage was further reduced during World War II when ammonia was in short supply.

Chloramines were then used sparingly until the 1970s when trace organic chlorination by-products were discovered (THMs). As discussed earlier in this chapter, THMs are produced from the reaction of chlorine with natural organic materials (humic and fulvic acids) and were also identified as possible carcinogens.

Subsequent to the discovery of THMs in drinking water, chloramination received renewed attention because it produces less THMs than *free* chlorine under most conditions. Haloacetic acids (HAAs) were identified as chlorination disinfection by-products and a group of five of these compounds were regulated in 1998. This further supported the use of alternate disinfectant such as chloramines.

A common disinfection strategy is to provide primary disinfection with chlorine or another strong disinfectant and then use chloramine as the residual disinfectant. This combination reduces chlorine by-product formation that would occur in the distribution system but still satisfies the need to ensure microbiologically safe drinking water. The widespread use of chloramines may be affected in the future, however, as new information is available on the by-products of chloramination.

Table 1-1 Utilities with long experience of chloramines use

| City | Approximate Start of Chloramination |
|-----------------------|-------------------------------------|
| Denver, Colo. | 1917 |
| Portland, Ore. | 1924 |
| St. Louis, Mo. | 1934 |
| Boston, Mass. | 1944 |
| Indianapolis, Ind. | 1954 |
| Minneapolis, Minn. | 1954 |
| Dallas, Texas | 1959 |
| Kansas City, Mo. | 1964 |
| Milwaukee, Wis. | 1964 |
| Jefferson Parish, La. | 1964 |
| Philadelphia, Pa. | 1969 |
| Houston, Texas | 1982 |
| Miami, Fla. | 1982 |
| Orleans Parish, La. | 1982 |
| San Diego, Calif. | 1982 |

Source: Trussell and Kreft 1984.

EVOLUTION OF CHLORAMINATION MATERIALS

The first observations of chloramine formation were in waters that contained ammonia. In addition, wastewater disinfection with chlorine often resulted in the formation of chloramines. Ammonia was initially added to water as aqua ammonia (liquid ammonium hydroxide) or ammonium salt solutions. Precipitation of calcium from water near the point of application prevented the widespread use of compressed ammonia gas. This issue was resolved and the use of anhydrous ammonia (gas) is now commonplace. The four forms of ammonia currently in common use are anhydrous ammonia (NH₃), aqua ammonia (NH₄OH), ammonium chloride (NH₄Cl), and ammonium sulfate ([NH₄]₂SO₄).

EVOLUTION OF CHLORAMINATION CONTROL PRACTICES

Chloramine residual testing was conducted originally using the same methods used for free chlorine. The total residual was determined by iodometric titration. It wasn't until the use of orthotolidine that speciation of the various forms of residual chlorine could be determined. This led to improvements in the dosage control of both chlorine and ammonia. Subsequently, the development of amperometric differential titration led to an even better understanding of the chemistry of the chlorine residual compounds. Today DPD is the most common test indicator for chlorine residual analysis, and it is possible to use DPD to differentiate some chloramine compounds.

Improvements in ammonia testing have also been important to control excess ammonia and to verify optimum chlorine:ammonia feed ratios. The Nessler method was used as early as 1930 to analyze wastewater for ammonia. This method used the formation of iodine and its characteristic color to determine the concentration of ammonia. The phenate method provides an alternative when some interferences are present. The ammonia-selective electrode method, developed in the 1970s, has made the routine testing of ammonia in water possible.



DISINFECTION REGULATIONS IN THE UNITED STATES

In 1974, the United States passed the Safe Drinking Water Act (SDWA). Amendments were added in 1986 and again in subsequent years that set further criteria for acceptable levels of THMs (Connell 1996). The SDWA also encouraged alternate treatment methods to achieve the now twin goals of disinfection and minimized THMs.

The Disinfectants and Disinfection By-Products Rule (USEPA 2001) established a maximum contaminant level (MCL) for THMs of 80 µg/L. The same rule set the MCL for HAAs at 60 µg/L. Maximum residual disinfectant levels were also set at 4.0 mg/L (ppm) for both chlorine and chloramine.

These regulations have caused utilities to carefully manage the use of chlorine. For example, the use of chlorine at the raw water intake is being reconsidered in favor of moving the point of addition closer to the clearwell. Intermediate points in the treatment plant would be considered on an as-needed basis. The addition of chlorine in conjunction with ammonia for use as the residual disinfectant in the distribution system is gaining popularity.

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INTERNATIONAL DISINFECTION REGULATIONS

The World Health Organization (WHO) is a specialized agency of the United Nations. It publishes guidelines for drinking water quality that are used as a basis for the development of national drinking water standards. The 1998 guidelines include limits for disinfectants and disinfection by-products.

The European Union (EU) issued a directive (98/83/EC) that established minimum standards for water intended for human consumption. (More strict standards within the member states are allowed.) The directive includes disinfectants and disinfection by-product limits similar to the WHO guideline values.

The Netherlands has water systems operating without a residual in the distribution systems, indicating its great concern about the formation of THMs and other chlorinated by-products. The Netherlands' practices are not generally shared by the other European members. However, most of the practices of the EU states in the treatment of surface waters involve pretreatment with either ozone or chlorine dioxide, followed by chlorination of the finished waters.

Many countries have established their own drinking water quality standards. Most of these have adopted USEPA, EU, WHO, or a combination for their standards, yet the enforcement of standards varies widely from entirely voluntary to strict governmental oversight.

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THE FUTURE

Chlorination practices will continue to be under scrutiny as more is learned about the effects of the disinfection process and the resulting disinfection by-products. Operation of surface water treatment plants and the quality of the water they produce will continue to be followed closely. Treated, potable water will continue to be examined in ever-increasing detail. New processes that will remove organic precursors will be discovered and used successfully.

Disinfection of drinking water is a vital component of the treatment and delivery system, and the protection of public health is the primary function of drinking water purveyors. It is a great challenge to provide microbiologically safe water and at the same time control disinfectant by-product production. Currently, scientific information is available to achieve these competing objectives. Further advancements, from scientific research, will undoubtedly lead the use of chlorine and chloramines in new directions in the future.

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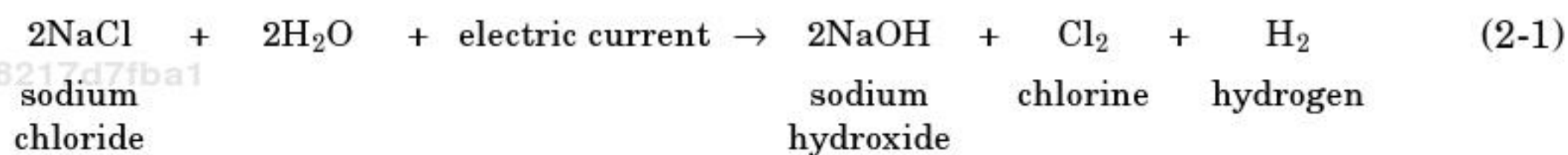
Chapter 2

Properties of Chlorination Chemicals

CHLORINE GAS

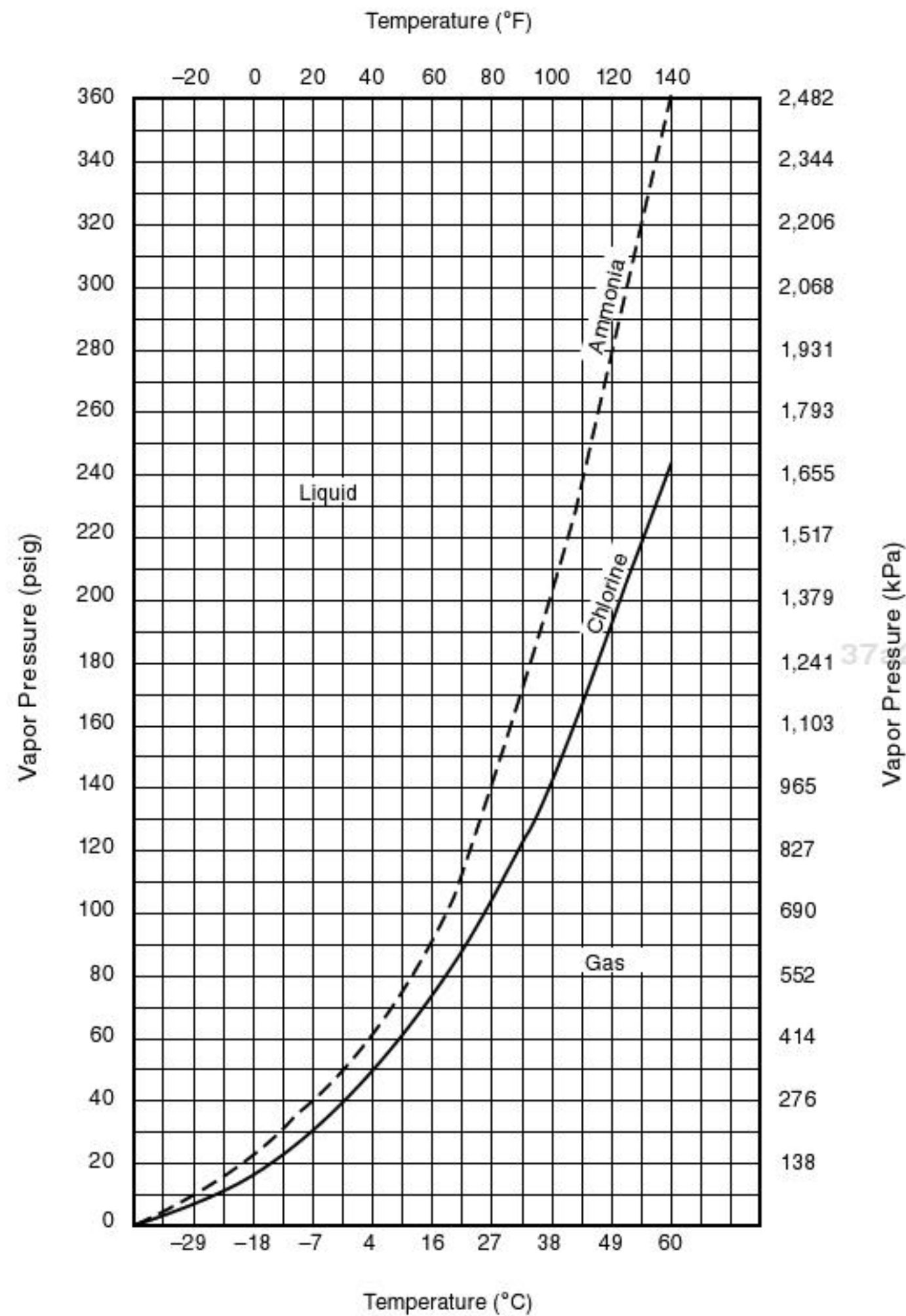
In the gaseous state, chlorine is greenish-yellow in color and has a pungent odor. The chemical symbol for chlorine is Cl and its atomic weight is 35.46. Chlorine, however, exists only as a two-atom molecule that is identified by the symbol Cl₂ and has a molecular weight of 70.92. It is neither explosive nor flammable, although as a strong oxidant, it supports combustion and reacts violently with many substances.

Pure chlorine does not exist naturally because of its reactivity. It is commercially produced by the electrolysis of sodium chloride brine. The chemical reaction is



Chlorine is stored and shipped as a liquefied gas under pressure, usually in 100- to 150-lb (45- to 68-kg) cylinders, ton containers, and tank cars. The compressed liquid is amber in color and approximately 1.5 times as heavy as water. If liquid chlorine is unconfined, it rapidly vaporizes to a gas. (One liquid volume yields approximately 450 volumes of gas.) The conversion of liquid to gas and subsequent expansion requires heat and can be self limiting by heat transfer to the liquid. As such, heat transfer through container walls limits gas withdrawal rates.

Because chlorine in a container may exist in gas, liquid, or both forms, any consideration of liquid chlorine includes that of chlorine gas. Chlorine gas is approximately 2.5 times as heavy as air. Therefore, released gas will initially settle to the lowest point in the container until mixed with the surrounding air. Figure 2-1 illustrates the temperature–pressure characteristics of chlorine. Note that when chlorine temperature increases, pressure also increases.



Source: Connell, 1996.

Figure 2-1 Vapor pressure of liquid chlorine

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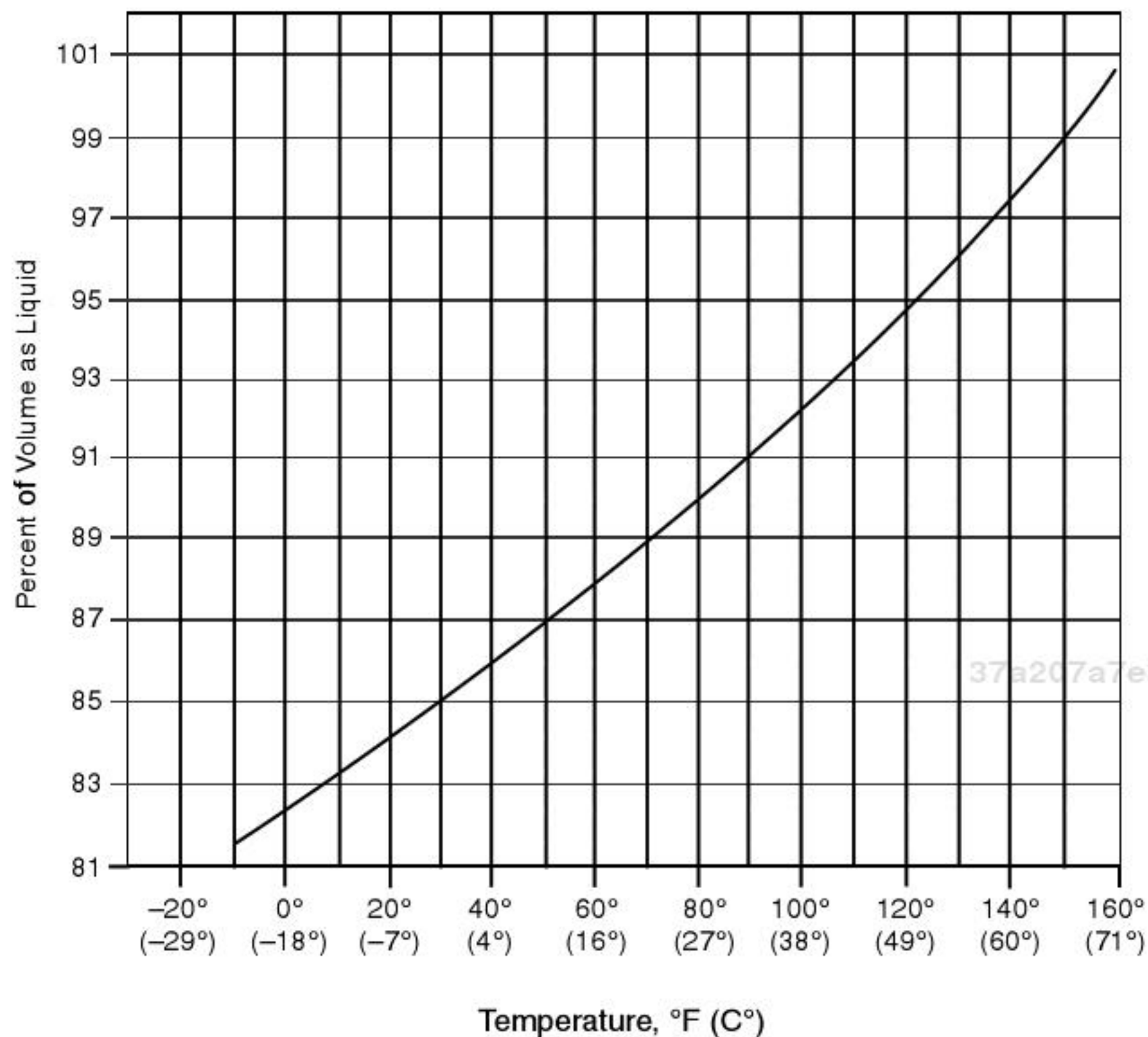
Figure 2-2 illustrates the volume–temperature characteristics of chlorine in a container loaded to the maximum authorized by the US Department of Transportation (USDOT). Note that a shipping container filled to its authorized maximum becomes completely full of liquid at approximately 154°F (68°C). Temperatures beyond that point may produce pressure that could result in hydrostatic rupture of the container. As such, safety devices are an integral part of chlorine containers. Fusible plugs are designed to melt at temperatures between 158 and 170°F (70 and 77°C), relieving excessive pressure accompanying temperature increases.

Chlorine is only slightly soluble in water; its maximum solubility is approximately 1 percent (10,000 ppm [mg/L]) at 49.3°F (9.6°C). Because the vapor pressure of chlorine increases with rising temperature, its solubility also decreases. The solubility drops to 4,000 ppm at 100°F (38°C) and to 0 ppm at 212°F (100°C). At temperatures below 49.3°F (9.6°C), chlorine can combine with water to form chlorine hydrate (sometimes called chlorine “ice”), which is a crystalline substance that may cause operational problems with direct feed chlorination. The maximum solubility for a given temperature should only be used for reference purposes. The actual useful solubility with minimal vapor pressure is considerably less: 3,500 mg/L is typically used as the maximum practical limit.

Table 2-1 summarizes some of the important physical properties of chlorine.

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Adapted from the Chlorine Institute Chlorine Manual.

Figure 2-2 Volume–temperature relation of liquid chlorine in a container loaded to its authorized limit

Table 2-1 Physical properties of chlorine

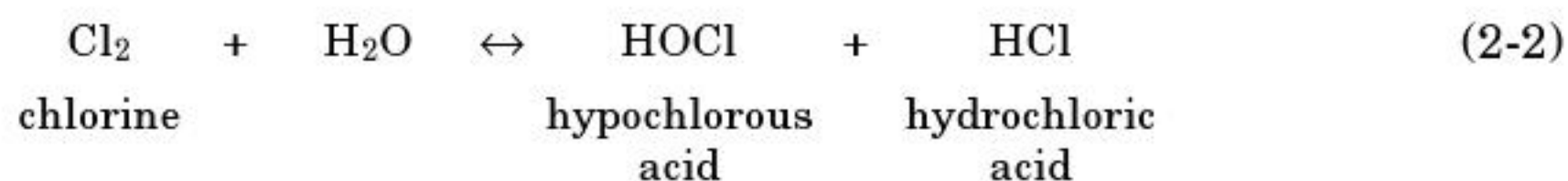
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| Boiling point (liquefying point) at 1 atm* | -29.15°F (-33.97°C) |
| Melting point (freezing point) at 1 atm | -149.76°F (-100.98°C) |
| Liquid density at 60°F (16°C) | 88.8 lb/cu ft (1,422 kg/m ³) |
| Gas density at 34°F (1.1°C) | 0.2006 lb/cu ft (3.213 kg/m ³) |
| Specific gravity (liquid) at 32°F (0°C) | 1.468 (water = 1) |
| Specific gravity (gas) at 32°F (0°C) | 2.485 (air = 1) |
| Water solubility at 70°F (21.1°C) | 0.7 percent |
| Vapor pressures: | |
| at 32°F (0°C) | 53.51 psi (368.9 kPa) |
| at 77°F (25°C) | 112.95 psi (778.8 kPa) |
| at 129°F (43.9°C) | 191.01 psi (1,316.8 kPa) |

*1 atmosphere = 14.696 psi (101.325 kPa).

Chemical Properties

Although it is neither explosive nor flammable, chlorine is a strong oxidant and capable of supporting combustion of certain substances. It should be handled and stored away from other compressed gases (e.g., ammonia) and flammable materials.

When mixed with moisture or water, chlorine will hydrolyze to form a corrosive mixture of acids and strong oxidants shown as



The chemical reactivity of chlorine enables it to combine with many other chemicals. It reacts with most organic materials, sometimes with explosive results. Dry chlorine is not corrosive to metals such as carbon steel, nickel, lead, or copper, but it can react violently with other metals such as aluminum, tin, gold, and titanium. Stainless steels are subject to chloride stress corrosion and should not be used by water utilities for chlorine service. Moist chlorine is corrosive to most metals with the exception of gold, silver, platinum, titanium, and certain specialized alloys.

Some plastics, such as polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF), can be used with gaseous chlorine whether wet or dry. Dry liquid chlorine or gas under pressure will react with polyvinyl chloride (PVC), causing it to soften and reduce its structural integrity. PTFE and PVDF may be used in liquid chlorine service. Gaseous chlorine under vacuum, both wet or dry, is compatible with PVC, chlorinated polyvinyl chloride (CPVC), or acrylonitrile butadiene styrene (ABS).

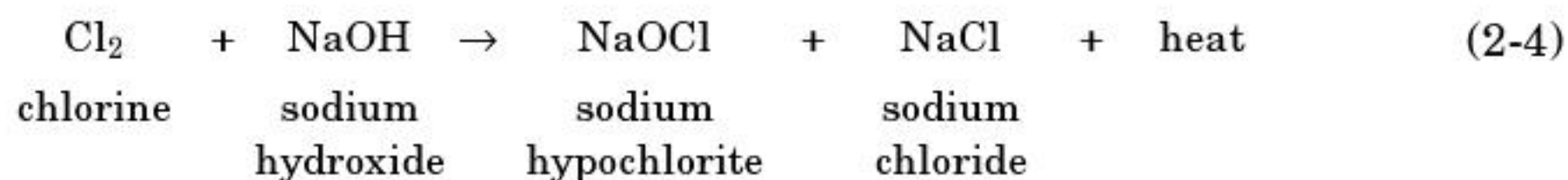
SODIUM HYPOCHLORITE

Sodium hypochlorite (NaOCl), often referred to as liquid bleach, is available only as a solution that contains 5–20 percent available chlorine. These solutions are clear to light yellow in color, are alkaline corrosive, and have a strong chlorinous odor. (The vapor above solutions contains a mixture of hypochlorous acid and chlorine monoxide.) The percent concentration typically used with hypochlorite is in terms of “trade percent.” This is different from a “weight percent,” which takes into consideration the solution’s specific gravity. Trade percent is expressed as

$$\text{trade percent} = \frac{\text{chlorine (g/L)}}{1,000} \times 100 \quad (2-3)$$

A 15 percent solution contains 1.5 lb/gal (180 g/L) of chlorine; a 10 percent solution contains 1 lb/gal (100 g/L), and so on.

Sodium hypochlorite is produced by reacting chlorine and sodium hydroxide as follows:



As noted earlier in this chapter, heat is generated during this reaction, which must be controlled to minimize the formation of chlorate at the onset and maximize stability during storage.

Unlike elemental chlorine, sodium hypochlorite is subject to decomposition. Table 2-2 lists the primary factors that affect stability.

Table 2-2 Primary factors affecting sodium hypochlorite stability

| Factor | Relationship | Decomposition Products |
|---------------------|--|-------------------------|
| Concentration | Stability increases inversely with concentration | Chlorate |
| Temperature | Stability increases inversely with temperature | Chlorate |
| Metallic impurities | Minimize Cu, Ni, Co concentrations | O ₂ |
| pH | A pH between 11.5 and 13 is best | Chlorate |
| UV light | Minimize light exposure | Chlorate/O ₂ |

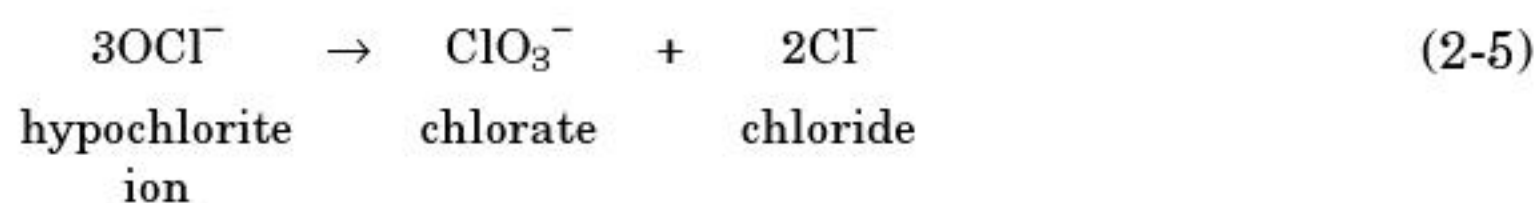
Based on the influencing factors listed in Table 2-2, the rate of decomposition of liquid hypochlorite has been studied (Gordon et al. 1995; Bommaraju 1994), and several equations have been developed to help predict the decomposition rate. (For additional details see the *Sodium Hypochlorite Manual* [Chlorine Institute 1995].) While helpful, these equations rely on a number of assumptions as well as accurate and consistent information, all of which may not be available. The best method to use in dealing with decomposition is to minimize the negative factors outlined in Table 2-2 and monitor the solution concentration. For a crude estimate, under moderate conditions, a 15 percent hypochlorite solution can conservatively be expected to degrade by approximately 0.5 percent per day. For example, 15 percent sodium hypochlorite at 77°F (25°C) has a 100-day half-life (i.e., it will degrade to half of its strength in 100 days). For comparison, at the same temperature, the half-life of 10 percent sodium hypochlorite is 220 days, and 5 percent is 790 days.

The three implications to sodium hypochlorite decomposition include

- the slow degradation of feed concentration,
- possible health consequences of high chlorate levels, and
- the evolution of oxygen that may complicate the feed.

Because sodium hypochlorite solution concentration degrades with time, feed volumes must be increased to compensate. This is easily accomplished by adjusting the volumes manually (once a week is adequate under most conditions), or by providing residual feedback control as outlined in chapter 4. Concentration of new shipments of sodium hypochlorite should be checked daily for the first few days until stability can be characterized.

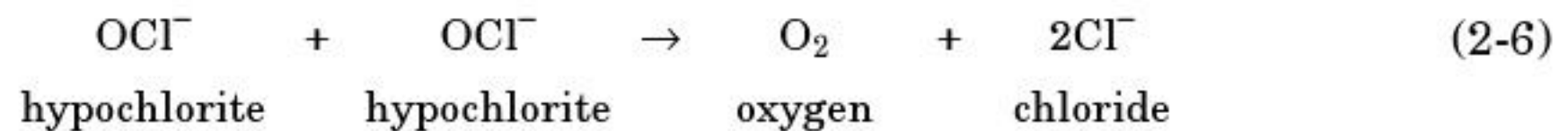
Chlorate is a by-product of decomposition, formed in the manufacturing process and during storage, as illustrated here:



The human health risk of chlorate has not been clearly defined in any definitive studies. For example, the 2002 edition of the *Drinking Water Standards and Health Advisories* (USEPA 2002) does not contain a listing for chlorate. However, high levels of chlorate have been associated with hemolytic anemia. Health Canada has proposed a guideline for chlorate in drinking water of 1.0 mg/L and the World Health Organization has a provisional guideline of 0.7 mg/L.



A second major degradation path, primarily catalyzed by transition metals such as Ni^{2+} , Cu^{2+} , and Co^{2+} , produces oxygen as follows:



While oxygen is not toxic, this degradation pathway can dramatically reduce the solution half-life and gas-bind chemical feed pumps resulting in cavitations and irregular feed rates. Metal concentrations in the sub-ppm levels can be a problem. Contamination can result from the manufacturing process, storage, transportation, feeding, or via dilution water. Particulates can be a major source of metal contamination, and filtration during the storage tank fill process can be an effective preventative measure. All metal (with the exception of titanium and tantalum) contact must be eliminated from storage vessels, piping, valves, and feed equipment.

Steps to Reduce Hypochlorite Degradation

Regardless of any other factors, sodium hypochlorite solutions will degrade with time. Any steps to minimize the time between manufacture, delivery, and use will maximize product strength and reduce chlorate formation. These steps will, however, involve trade-offs in product cost and operation time between deliveries.

The products of decomposition of most concern are chlorate and oxygen. There is no specific data showing that the expected levels of chlorate from hypochlorite would be hazardous to human health. However, it is prudent to minimize the formation of unintended by-products that may be of future concern. Oxygen, on the other hand, while not a toxicity issue, can complicate feeding.

A small reduction in hypochlorite solution concentration will greatly increase solution stability, as outlined in Table 2-3. However, care must be exercised to dilute hypochlorite solutions only with good quality waters. Using water that has been filtered and passed through a softener (cation exchange resin) to remove any solubilized metals is a good precaution. The pH must also be between 11.5 and 13.

Decreasing the temperature of hypochlorite solutions also has substantial benefit. As shown in Table 2-3, a 59°F (15°C) decrease in temperature increased stability over six times. While solution temperature is primarily a result of storage conditions, and options to reduce temperature may be limited, any reduction in temperature will have a measurable positive effect on solution stability. Such options may include

- specifying a maximum temperature of delivered hypochlorite,
- avoiding daylight heating by covering storage containers and feed piping, and
- considering practical heat exchangers and cooled storage areas.

Both oxygen and chlorate formation are catalyzed by ultraviolet (UV) light (sunlight). At the very least, the storage facility should be covered, preferably with reflective material, and storage containers made of or covered with opaque or UV blocking material.

Table 2-3 Half-life values of liquid bleach: varying temperature, pH, and concentration

| Temperature | | 9.5 wt% | 4.25 wt% | 2.13 wt% |
|-------------|------|-----------|-----------|----------|
| (°F) | (°C) | pH 13.0 | pH 12.7 | pH 12.4 |
| 95 | 35 | 66 days | 300 days | 2 years |
| 68 | 20 | 1.5 years | 6.5 years | 17 years |

Utilities should also establish minimum specifications for sodium hypochlorite deliveries to help in minimizing degradation products and rates. A hypochlorite specification may include the following requirements:

- a pH greater than 12,
- Ni^{2+} and Cu^{2+} concentrations less than 0.1 mg/L,
- a maximum chlorate concentration,
- a concentration greater than 12.5 percent (consider a lower concentration if cost per pound is comparable and feed and storage capacity can accommodate), and
- a solution temperature prior to delivery that is below 77°F (25°C).

The enforcement of a specification will greatly assist solution stability and predictability of degradation rate. For more detailed specification information, readers are directed to the AWWA Standard for Hypochlorites (B300, latest edition).

AMMONIA GAS

Ammonia is a gas at atmospheric pressure and ambient temperatures. It is not an element but rather a compound composed of the elements nitrogen and hydrogen. The chemical formula for ammonia is NH_3 and contains three atoms of hydrogen and one atom of nitrogen. Its molecular weight is 17. Small quantities of ammonia exist naturally. For commercial purposes, ammonia can be synthesized by a number of different processes that use hydrogen and nitrogen.

Ammonia has a pungent odor and, unlike chlorine, is colorless in both gaseous and liquid states. Ammonia liquefies at approximately the same temperature as chlorine but has a higher vapor pressure than chlorine at corresponding temperatures. The vapor pressure–temperature curve for ammonia is shown in Figure 2-1. To illustrate the difference in vapor pressure between chlorine and ammonia with changing temperatures, the dotted line in the figure represents the ammonia vapor pressure curve. The vapor pressure of ammonia is approximately 20 percent greater than chlorine at ambient temperatures and increases at a more rapid pace than chlorine at higher temperatures.

Unlike chlorine, reliquefaction of ammonia gas is not considered to be an operational problem. The boiling point, or vaporization point, of ammonia at atmospheric pressure is -28°F (-33.3°C).

Liquid ammonia is lighter than water with a density of 42.57 lb/ft^3 (681.9 kg/m^3) at -18°F (-28°C). Ammonia gas is lighter than air with a density of 0.555 lb/ft^3 (0.8899 kg/m^3) at -18°F (-28°C). Ammonia is approximately 36 times more soluble in water than chlorine: 250 lb/100 gal (299 g/L) or 34 percent by weight at 60°F (20°C).

Ammonia is classified by the USDOT as a corrosive gas. Chemically, ammonia is a relatively stable chemical compound and reactive only under specific conditions or with certain chemicals. Most common metals are unaffected by dry ammonia. In the presence of moisture, or when dissolved in water, ammonia will attack copper, zinc, and alloys containing these metals (e.g., brass and bronze). Ammonia will react with organics and inorganics to form ammonium salts. Reactions with chlorine can produce dangerous and/or explosive compounds, such as nitrogen trichloride. The physical properties of ammonia are listed in Table 2-4.

Ammonia is considered a respiratory irritant, although it does not have a cumulative effect. Ammonia's pungent odor provides an early warning to alert the individual to its presence. Although individual physiological responses may vary, the least perceptible odor is considered to be 5 ppm (by volume). The current (1993) OSHA-PEL level is 35 ppm, while the American Council of Government Industrial Hygienists (ACGIH) threshold limit value and short-term exposure limit (STEL) value are 25 ppm and 35 ppm, respectively.

Table 2-4 Physical properties of ammonia

| | |
|------------------|--|
| Molecular Weight | 17.03 |
| Boiling point | -28.2°F (-33.4°C) at 1 atm |
| Freezing point | -107.9°F (-77.7°C) |
| Density (gas) | 0.0555 lb/ft ³ (0.8899 kg/m ³) at -27.7°F (-33.2°C) |
| Density (liquid) | 42.57 lb/ft ³ (681.9 kg/m ³) at -27.7°F (-33.2°C) |
| Flammability | Only within a range of 16–25 percent |

Source: Compressed Gas Association 1984.

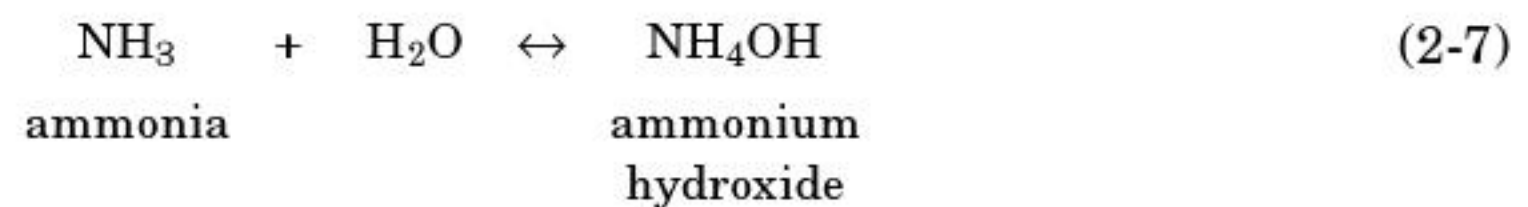
Table 2-5 Properties of aqueous (aqua) ammonia, 30 percent by weight

| | |
|--------------------------------------|---|
| Specific gravity at 60°F (15°C) | 0.8957 |
| Density at 60°F (15°C) | 26.31°Bé (Baumé) 55.7 lb/ft ³ (0.893 kg/L) |
| Boiling point at 1 atm (101.325 kPa) | 82°F (27.8°C) |

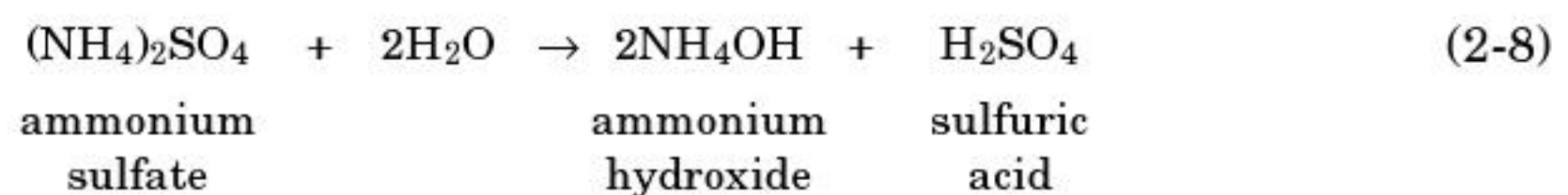
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AMMONIA SOLUTIONS

Ammonia is available in forms other than as a compressed gas in cylinders. The most commonly used form is a solution of ammonia dissolved in water, usually referred to as aqueous or aqua ammonia. Other forms of ammonia are salts of ammonia solutions. Of these, the most frequently used is ammonium sulfate. The reaction of ammonia with water is shown here:



The product of this reaction is ammonium hydroxide, which is also produced from solutions of ammonia salts, as shown here:



Equation 2-7 is reversible and will release ammonia as a gas. In addition, solutions that produce ammonium hydroxide will also provide ammonia. Because ammonia is available from these solutions, ammonium salt solutions are used as a source of ammonia just as sodium hypochlorite is used as a source of chlorine. All ammonium salt or aqueous ammonia solutions have alkaline pH values. (The exact pH is a function of the solution concentration and temperature.) Because some ammonia gas evolves, a vapor pressure exists in aqueous ammonia and ammonium salt solutions, and all storage facilities must be suitably vented. Table 2-5 lists the properties of aqueous ammonia.

Both ammonium salt solutions and aqueous ammonia exhibit the same characteristics that would be expected from ammonia. The solutions should be treated as a respiratory irritant and handled with care. Irritation and redness may develop if the solutions come into contact with the skin.

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For additional information on the properties and handling of chlorine, ammonia, and their solutions, see chapter 6. Also ask the chemical supplier to provide the latest available material safety data sheet (MSDS) for the appropriate chemical.

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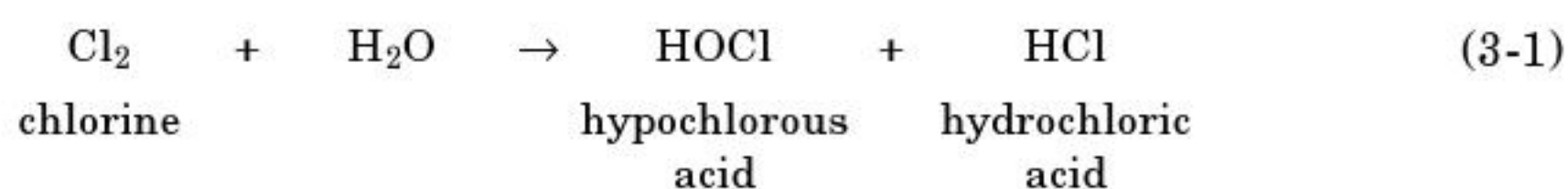
Chapter 3

Chlorination Water Chemistry and Disinfection Mechanisms

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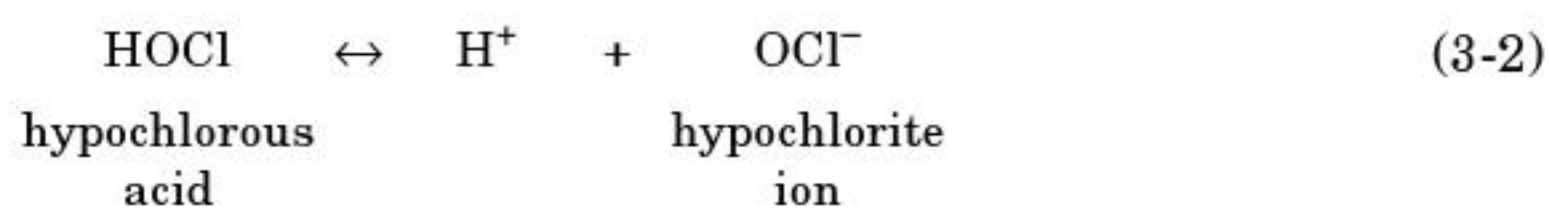
CHLORINATION CHEMISTRY

When chlorine gas (Cl_2) is added to water, a mixture of hypochlorous acid (HOCl) and hydrochloric acid (HCl) is formed, as shown here:

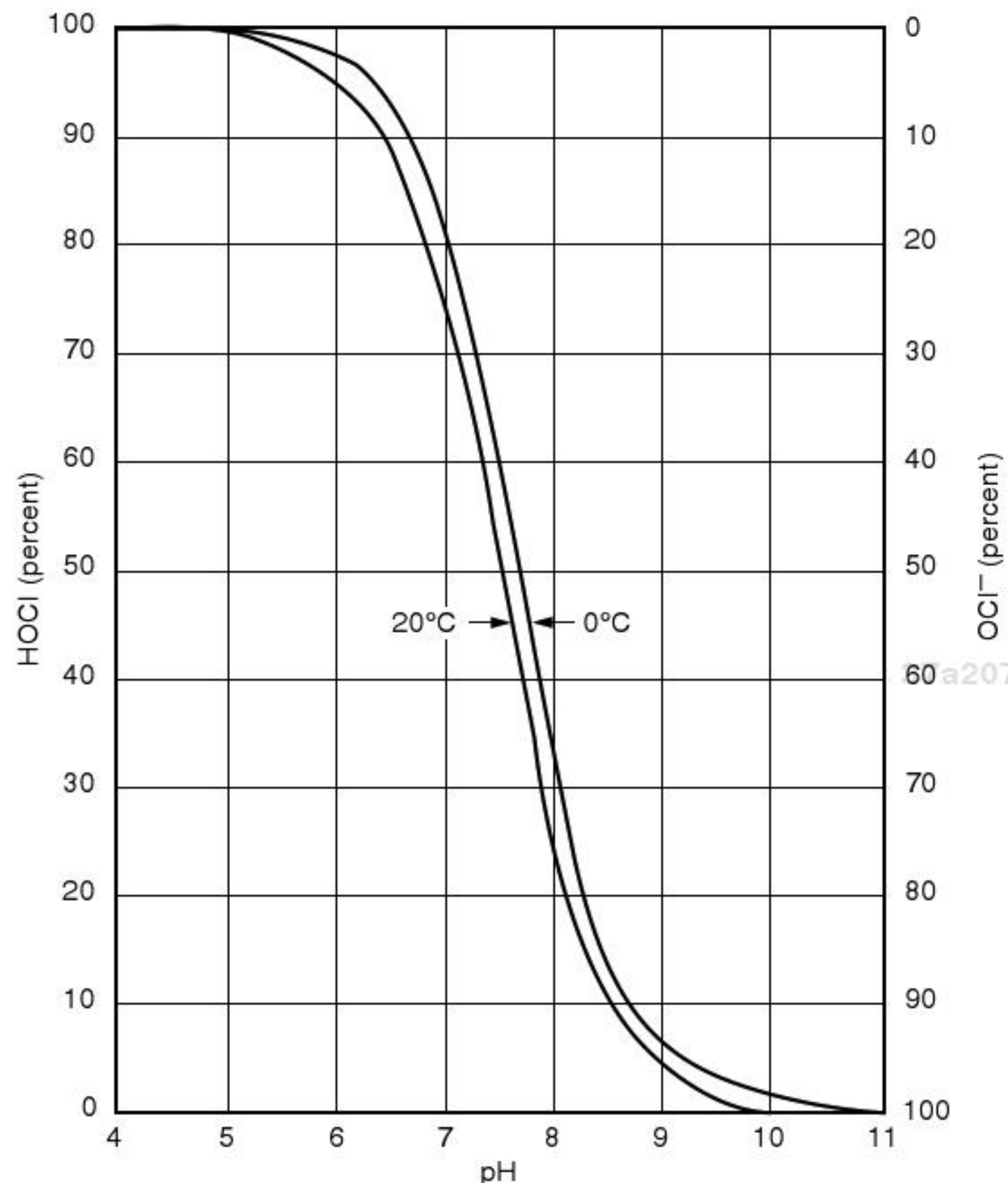
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In dilute solutions and at pH levels above 4, the reaction illustrated in Eq 3-1 is displaced to the right. As the pH drops below 4, the percentage of available chlorine in the form of chlorine gas increases along with the vapor pressure. For every milligram per liter (part per million) of chlorine added, 0.7–1.4 mg/L of alkalinity is consumed. At typical chlorine dose rates (1–5 mg/L), the pH of the receiving water will be reduced but buffered by the water's natural alkalinity.

Once formed the HOCl instantaneously establishes equilibrium as follows:



As the pH rises above 7.5 (60°F [20°C]), an increasing percentage of free chlorine is in the form of hypochlorite ion. At a pH below 7.5, free chlorine is in the form of HOCl, as illustrated in Figure 3-1. As shown, temperature will also influence the equilibrium; the effect is particularly significant at a pH between 7 and 8. This reaction is independent of concentration, is completely reversible, and responds instantaneously to pH changes.



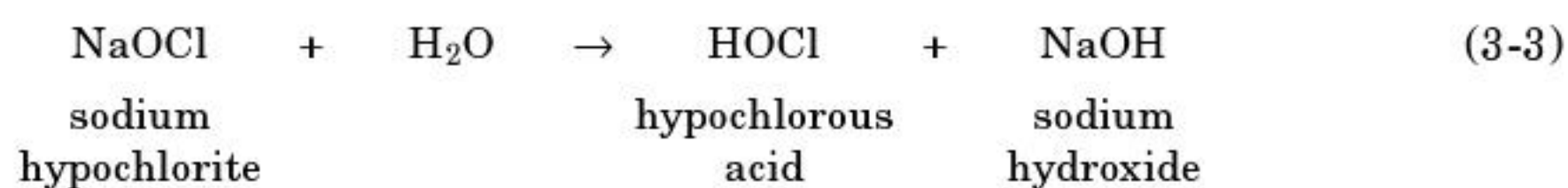
Source: Connell, 1996.

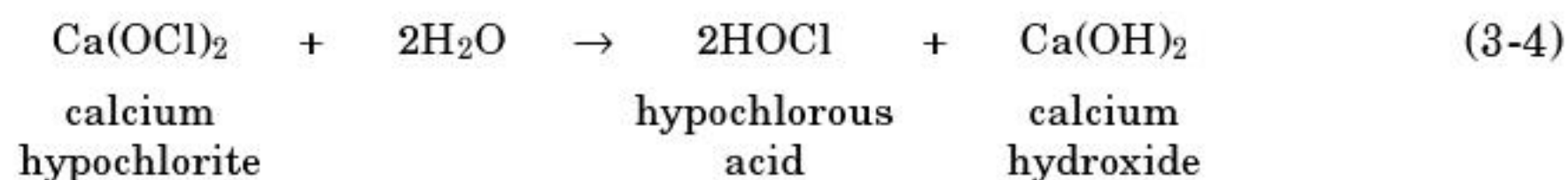
Figure 3-1 Hypochlorous acid/hypochlorite distribution versus pH

The combined concentration of HOCl and OCl⁻ is known as *free chlorine residual* (FCR). These two species, however, react quite differently. HOCl is a much stronger disinfectant, stronger oxidant, and more reactive than OCl⁻. HOCl will disinfect 100 times faster and oxidize compounds that OCl⁻ will not, but be consumed at a much higher rate. This creates a dynamic relationship in which HOCl is consumed and the remaining FCR re-equilibrates according to the relationship illustrated in Figure 3-1. In effect, OCl⁻ acts as a disinfectant buffer, adding HOCl as it is being consumed.

The speed of chlorine disinfection and durability of the residual is therefore strongly affected by the pH of the water being treated. In addition to being more reactive, HOCl is neutral and can more easily penetrate negatively charged bacterial surfaces and suspended particles protecting pathogens.

Chlorine may also be added as sodium hypochlorite or calcium hypochlorite. While there are obvious differences in feeding characteristics, and hypochlorite will add alkalinity as opposed to chlorine gas consuming alkalinity, once added to the receiving water the resulting residuals are indistinguishable from those added by chlorine gas as shown here:



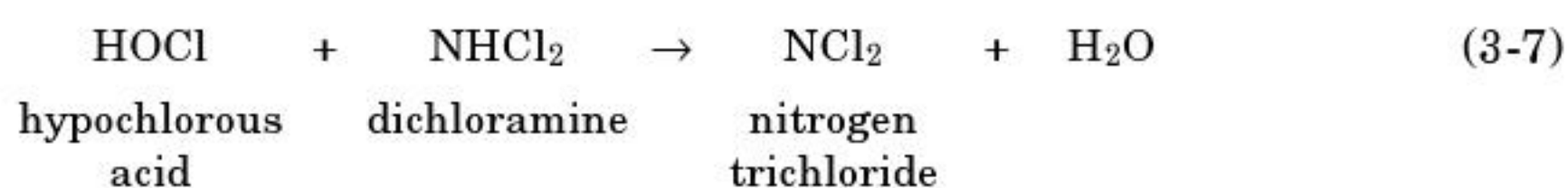
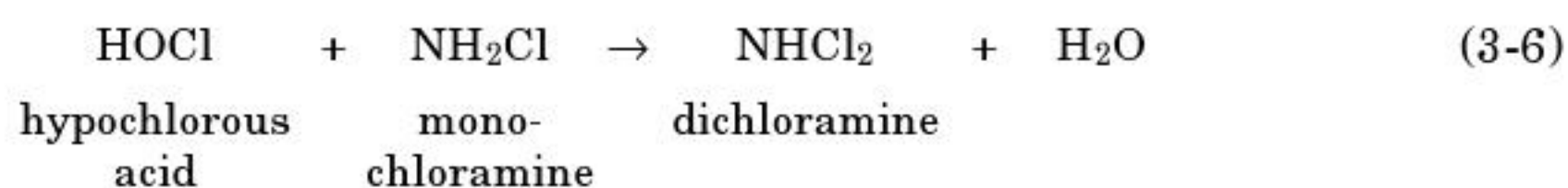
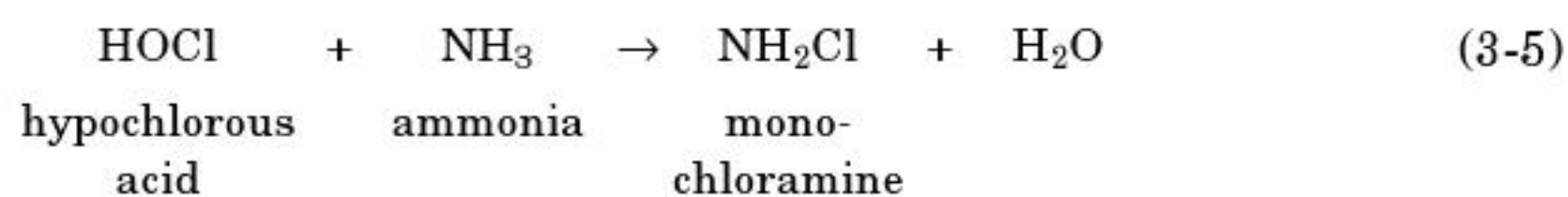


The reaction products of both chemicals produce HOCl, which will be distributed according to the HOCl and OCl⁻ pH relationship.

Chlorine Reactions With Other Compounds

The reactions of chlorine with other compounds are important to understand because these reactions generally exhibit a chlorine demand. This may directly affect the disinfection capability of the chlorine added to the water.

Reactions with ammonia. The reaction between chlorine and ammonia is of great significance in water chlorination processes, especially disinfection. When chlorine is added to water containing natural or added ammonia, the ammonia reacts with HOCl to form various chloramines that, like HOCl, retain the oxidizing capacity of chlorine (+1 oxidation state) but in a weaker configuration. The reactions between chlorine and ammonia may be represented as follows:



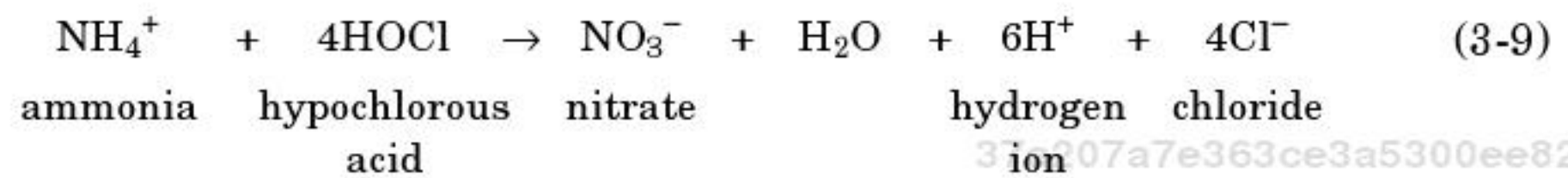
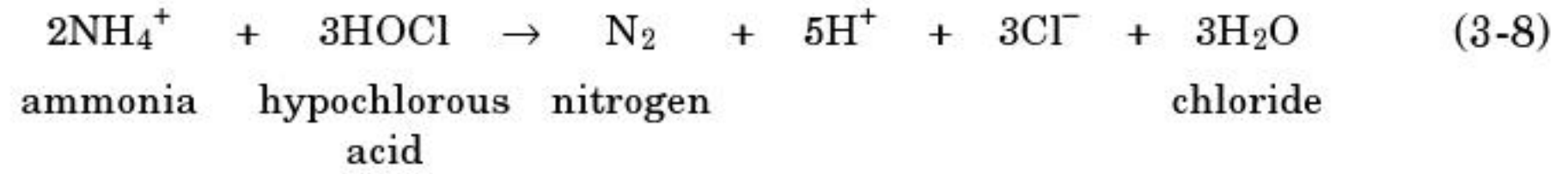
The distribution of the reaction products is governed by the rates of formation of monochloramine (NH₂Cl) and dichloramine (NHCl₂), which are dependent upon pH, temperature, time, and initial chlorine to ammonia (Cl:NH₃) ratio. In general, low Cl:NH₃ ratios and high pH levels favor monochloramine. Monochloramine is characterized as a weak disinfectant and oxidant, frequently used as a durable residual that will form lower levels of disinfection by-products (DBPs) and will produce the least detectable chlorinous taste and odor (T&O) of any of the chlorine residuals. Dichloramine has similar disinfection and oxidation characteristics to monochloramine but is characterized by a more intense T&O. Nitrogen trichloride (NCl₃) is practically insoluble in water, has a very intense T&O, and is known for its eye irritation/tearing effects at very low concentrations.

Chlorine also reacts with organic nitrogenous material, such as proteins and amino acids, to form organic chloramines. These compounds have little disinfection and oxidation value and are resistant to further oxidation. These residuals are sometimes referred to as "nuisance residuals" because they are virtually indistinguishable from inorganic chloramines with standardized analytical procedures.

The breakpoint reaction. The breakpoint is described as the point at which chlorine demand has been satisfied, combined chlorine compounds have been destroyed, and as additional chlorine is added, a free chlorine residual is produced. The breakpoint reaction is important in understanding the formation of chloramines (when ammonia is present or is added) because the formation of chloramines is a primary

element of this reaction. In some cases, organic compounds present in the water may also combine with chlorine to form chloro-organic compounds that may exhibit the characteristics of a combined chlorine residual.

If water contains ammonia (either naturally or added), and a free chlorine residual is desired, the ammonia can be removed by oxidation with chlorine to produce primarily nitrogen gas and some nitrate by the breakpoint reaction. While there are a number of reaction steps that take place in this process, two of the predominant reaction sequences are summarized as follows:



Ideally, the breakpoint reaction should take place at a pH between 7.0 and 7.5, but it will also continue at a slower rate down to a pH of 6.5 and as high as 8.5. Adequate chlorine must also be added to complete the reaction (empirically found to be approximately 8.5 mg/L [ppm] chlorine per mg/L [ppm] $\text{NH}_3\text{-N}$). Additional chlorine may also be required to satisfy a number of side reactions, including the creation of minor products such as nitrogen trichloride, and other chlorine demands (caused by organic and other compounds). The only other reaction requirement is time. The breakpoint reaction is not instantaneous and may take 30 min or longer to run to completion. If free chlorine disinfection or oxidation is needed, adequate reaction time must be provided.

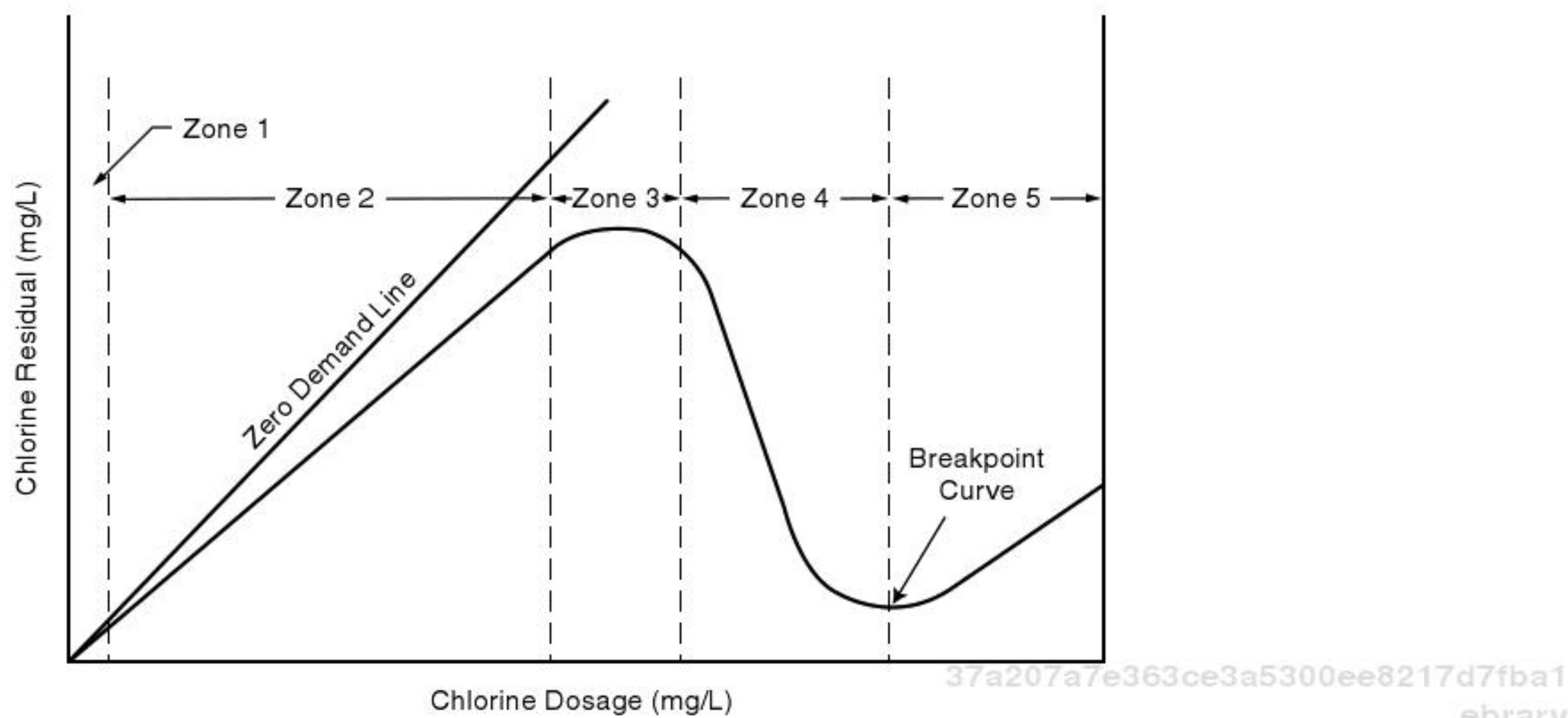
The ammonia breakpoint reaction is a series of steps in which monochloramine is formed first and then converted by HOCl to dichloramine, which is followed by a dichloramine decomposition reaction resulting in primarily nitrogen gas and nitrate. Organic compounds may combine with chlorine to form chloro-organic compounds that may also be destroyed as more chlorine is added.

The breakpoint curve illustrates the breakpoint reaction and is shown in Figure 3-2. This curve plots the chlorine dosage in milligrams per liter along the horizontal axis and the total (free and combined) chlorine residual in milligrams per liter along the vertical axis. The line plotted at a 45° angle is called the zero demand line and represents the ideal situation in which all chlorine added to the water is measured as a free chlorine residual in the water. In zero demand water, there is no loss of chlorine addition due to chlorine demand.

The presence of reducing agents and other inorganic chlorine demand-causing compounds will consume any initial chlorine dosage, which results in zero chlorine residual until this demand is satisfied. This section of the zero demand curve is identified as zone 1 in Figure 3-2. Once this initial demand is met in the presence of ammonia (and organic compounds), any additional dosage will be measured as combined chlorine residual. This residual will increase in proportion to the increase in dosage and is identified as zone 2. In this zone, monochloramine is the primary chlorine form.

As the chlorine-to-ammonia molar ratio surpasses 1:1, more and more dichloramine is formed, the dosage/residual relationship will cease to be linear, and the amount of combined and total residual increase will flatten out, as shown by zone 3. In this zone, the proportion of dichloramine increases to a point where it begins to decompose (along with any chloro-organic compounds that may have formed).





Source: Connell, 1996.

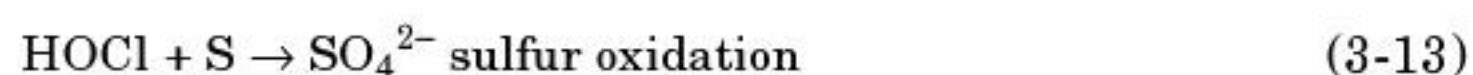
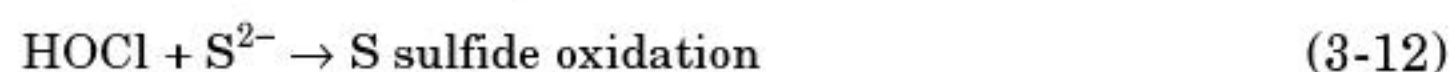
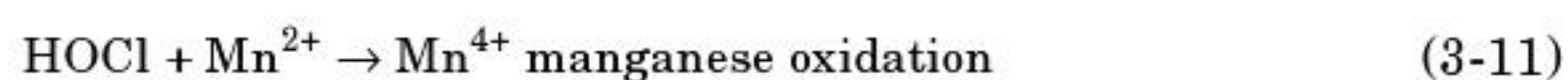
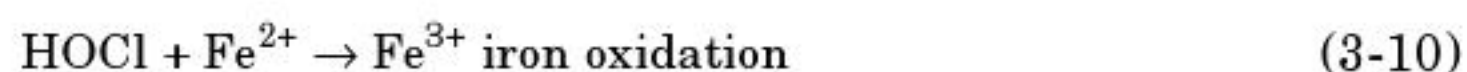
Figure 3-2 Breakpoint curve

Subsequent increases in chlorine dosage will convert an increasing proportion of monochloramine to dichloramine, which subsequently decomposes resulting in a roughly 2-mg/L drop in residual for each milligrams per liter added, as shown by zone 4. This continuing decrease of total residual will taper off and the chlorine residual will reach a minimum point after which it will once again increase with continued chlorine addition. This minimum point is called the *breakpoint* and represents that point in the treatment process at which all ammonia compounds (and most chloro-organic compounds) have been oxidized. Any further chlorine addition will increase the residual chlorine as free chlorine, as identified in zone 5. Combined chlorine residual predominates in zones 2, 3, and 4, while free chlorine residual predominates in zone 5. It is again important to point out that these reactions are not instantaneous. Time must be allowed for the reaction to go to completion before the results follow the breakpoint curve.

Some waters treated by the breakpoint process may never reach a zero residual because organic nitrogen compounds (or other chloro-organic compounds) present resist the oxidation by chlorine. This organic nitrogen is sometimes referred to as an *irreducible minimum*.

Each water plant must determine its own breakpoint curve. Analysis of the water for the various forms of chlorine at different chlorine dosages allows for the determination of the particular breakpoint curve for the water. Procedures from *Standard Methods for the Examination of Water and Wastewater* (APHA, et al., latest edition) should be followed for these determinations.

Inorganic oxidation reactions. The oxidation of soluble iron, manganese, and sulfides is a common use of chlorine in water treatment. Once oxidized iron, manganese, and sulfides form insoluble compounds, they then can be removed by filtration prior to distribution. The following are unbalanced equations that illustrate the oxidation products from chlorination:



When iron and manganese are oxidized, they are transformed from a colorless soluble ion to a red and a dark brown precipitate, respectively. If allowed to be oxidized by oxygen or chlorine addition at a customer's tap, the result is the staining of surfaces and cloths and, in some cases, the formation of scales that can eventually restrict flow. Iron is readily oxidized by both free and combined chlorine. Manganese is far more difficult to oxidize (requiring free chlorine, an optimal pH of 10, and 2–3 hr contact time). Approximately 0.6 mg/L chlorine is required to oxidize 1 mg/L of iron. (This reaction consumes 0.9 mg/L of alkalinity.) To oxidize 1 mg/L of manganese requires approximately 1.3 mg/L chlorine (3.4 mg/L alkalinity is consumed). Some organically combined manganese is even more resistant to oxidation.

Sulfide, primarily from wells, is highly toxic and produces a characteristic rotten-egg odor that makes the water unpalatable. With sulfides, there are two reaction steps possible. The first reaction, shown in Eq 3-12, produces colloidal sulfur. The second reaction, shown in Eq 3-13, produces a soluble sulfate ion that has no taste or odor and is not considered objectionable at low concentrations. Which reaction dominates will depend on the pH level and chlorine-to-sulfide ratio. The sulfate-forming reaction will be favored at a low pH (optimum 6.0) and high chlorine-to-sulfide ratio. Sulfur formation is favored at a high pH and low chlorine-to-sulfide ratio. Although oxidation of sulfide is relatively easy, the overall chemistry is complex and its removal without causing objectionable T&O can be difficult (requiring more elaborate treatment processes that are beyond the scope of this discussion).

Organic oxidation reactions. Reactions of chlorine with some organics produce DBPs. The most common are trihalomethanes (THMs). THMs include chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Some of these compounds are classified as probable human carcinogens (Fielding et al. 1993). The current maximum contaminant level (MCL) for THMs in drinking water is 0.080 mg/L (80 µg/L) (USEPA 1996). Another group of DBPs are haloacetic acids (HAAs), which include a number of compounds (11 or more). The five most common HAAs are grouped for regulatory purposes (dichloroacetic acid, monochloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid) and the MCL is 0.060 mg/L. Other products of chlorine-organic reactions have also been identified (Kleinjans 1991). Table 3-1 is a list of some of the generally recognized DBPs.

Table 3-1 Chlorination disinfection by-products

| Trihalomethanes | Haloacetic Acids |
|-------------------------|--------------------------|
| Chloroform | Dichloroacetic acid |
| Bromodichloromethane | Monochloroacetic acid |
| Dibromochloromethane | Trichloroacetic acid |
| Bromoform | Monobromoacetic acid |
| Haloacetonitrile | Dibromoacetic acid |
| Dichloroacetonitrile | Tribromoacetic acid |
| Trichloroacetonitrile | Bromochloroacetic acid |
| Bromochloroacetonitrile | Bromodichloroacetic acid |
| Dibromoacetonitrile | Dibromochloroacetic acid |
| Tribromoacetonitrile | Others |
| Cyanogen halides | Chloral hydrate |
| Halopicrins | Haloketones |

Source: Fielding et al. 1993.

Many factors influence the formation of DBPs, including contact time (CT), temperature, pH, precursor type and concentration, disinfectant type and concentration, ratio of oxidant to precursor, and concentrations of bromide and ammonia. In addition, naturally occurring humic and fulvic acids are known precursors for DBP formation.

Chlorine can be used as a preoxidant for the removal of T&O and color. Current regulations, however, limit the use of chlorine for this purpose because of the possible high production of undesirable DBPs. Generally, the use of pretreatment methods that remove DBP precursors or inhibit the formation of DBPs is the preferred water treatment strategy. These methods may include one or more of the following: filtration, lime softening, preoxidation with ozone, chlorine dioxide, permanganate, relocation of the point of chlorination, enhanced coagulation, membrane filtration, activated carbon treatment, or ultraviolet (UV) irradiation.

The reaction rates with organic compounds are generally slower than those with inorganic compounds and are often more difficult to quantify because the rate, demand, and end products may vary considerably with reaction conditions and type of precursor. The chlorine requirements are best established by laboratory jar testing to determine the desired treatment level.

Typically, chlorine requirements change periodically in surface water treatment plants. The complexity of new regulations may require pilot plant evaluation to effectively determine the best overall treatment and the most effective role for chlorine. When chlorine is used in the presence of organic compounds, the reaction products are of concern and the results should be reviewed with this in mind.

DISINFECTION MECHANISM

Disinfection is the treatment process used to destroy or inactivate disease-causing (pathogenic) organisms (Von Huben 1995). The consequences of waterborne disease range from mild illness to death. Disinfection should not be confused with sterilization. Sterilization is the complete destruction of all living microorganisms. It has been found that treatment for turbidity removal and subsequent disinfection to control disease-causing organisms is sufficient to protect public health.

Inactivating Pathogens in Water

Most pathogens are accustomed to living in the temperatures and conditions found in the bodies of humans and warm-blooded animals. In general, their ability to survive outside of this environment is limited, but some do survive long enough to cause infections if ingested in drinking water. Certain viruses and protozoans that form cysts can survive for surprisingly long periods, even under adverse conditions. Some pathogenic organisms also tend to be somewhat resistant to certain disinfection processes, so disinfection alone cannot always be assumed to ensure safe drinking water.

Some pathogens can be inactivated by simply storing water in open tanks for extended periods of time. Some pathogens are removed by sedimentation in those tanks, and others experience natural die-off. This is not usually a practical treatment method because of the large investment required for the storage facilities and reliability of the process. In addition, the water is subject to contamination and other nuisance organisms—such as algae—while in storage.

Water disinfection strategies are usually divided into two categories: surface water and groundwater. Surface water is characterized as containing a higher degree of suspended material, higher organic levels, diverse natural and man-made contaminants, variable quality, and subject to a wider variety of pathogens, including most notably *Giardia* and *Cryptosporidium*. Groundwater is generally characterized by low levels of organics and consistent quality. Groundwater is also subject to higher levels

and broader types of inorganic compounds, with viruses and bacteria being the pathogens of concern, albeit at low levels.

Surface water treatment is the more involved of the two because the water has not benefited from the natural filtering process of groundwater. Particulate matter (mineral and organic) as well as larger disinfectant-resistant organisms such as *Giardia* and *Cryptosporidium* must be removed by physical separation, primarily sedimentation and filtration. Higher organic levels and oxidation pretreatment requirements also require higher levels and longer contact times for oxidative disinfectants, which may aggravate DBP formation and complicate disinfection. Surface water may also be subject to rapid quality changes. It is not uncommon for surface water plants to use chlorine dioxide, ozone, or permanganate for oxidative pretreatment, followed by free chlorine disinfection and chloramine residual disinfection.

The longer contact time required for inactivation of *Giardia* and the outright resistance of *Cryptosporidium* to inactivation by chlorine present some of the most difficult disinfection challenges to water treatment operators. Treatment is further complicated by the difficulty in testing for these pathogens, making it almost impossible to monitor disinfection performance on a real-time basis. Treatment strategies generally involve a combination of filtration and disinfection designed to achieve a minimum total log reduction.

Disinfection of groundwater is far easier to achieve because water quality changes little over long periods of time. Disinfection programs are generally consistent and, therefore, easier to monitor and control. The pathogens of concern are viruses and bacteria that are relatively easy to inactivate. (Exceptions are in parts of the Southeast and in isolated aquifers elsewhere.) In most groundwater sources, the DBP precursor concentrations are generally low so that in many waters free chlorine can be used without risk of violating DBP regulations. However, it is important to point out that every water system has unique characteristics that must be taken into account to achieve the best water quality.

Detecting Pathogens in Water

Detecting various types of pathogens such as viruses and protozoan cysts is time-consuming and often requires involved analytical techniques. Alternatively, indicator organisms such as fecal coliform and total coliform are used for routine monitoring, and relatively simple, inexpensive tests are available for detecting their presence. These tests, however, only indicate the likelihood that water is contaminated by feces from a warm-blooded animal and, therefore, possibly contains pathogens. All public water systems are required by federal and state regulations to collect representative samples from the distribution system periodically for coliform analysis.

This inability to conduct routine tests for the presence of specific disease-causing microorganisms has been recognized in the US Environmental Protection Agency's (USEPA) Surface Water Treatment Rule, which is discussed later in this chapter. In essence, the rule requires a "treatment technique" for all systems using surface water sources. The technique must consist of one or more methods of treatment that will ensure almost complete removal and/or inactivation of the most resistant pathogenic organisms. In other words, establishing an MCL for pathogenic organisms is not practical because the tests for their presence cannot be completed in a timely manner. Compliance with regulations is based on properly operating the treatment process known to remove or inactivate the organisms.

DISINFECTION METHODS

A 1999 survey revealed the following US disinfection practices in larger water treatment plants (a large majority of smaller water treatment facilities generally use a form of chlorine):

| | |
|------------------------------|---------------|
| Chlorine gas | 83.3 percent* |
| Sodium hypochlorite | 18.3 |
| Sodium hypochlorite (onsite) | 2 |
| Chlorine dioxide | 8.1 |
| Ozone | 5.6 |
| Chloramines | 29.4 |
| UV | < 1 |

*The total percentage is greater than 100 percent because some utilities use several disinfection practices.

Although chlorination is the most common disinfection method, other methods are available and can be used in various situations as described in Table 3-2.

Refer to the *Interim Voluntary Security Guidance for Water Utilities* (AWWA 2004) when evaluating options for disinfection method.

Chemical Treatment

Although the primary use of chemical oxidants is for disinfection, these chemicals also serve other purposes during the disinfection process. In some cases, the choice of chemicals used in a treatment system is dictated by the ability of the chemicals to perform these secondary functions, which include

- control of biological growth in pipelines and basins;
- control of tastes and odors;
- removal of color;
- aids to flocculation; and
- oxidation of iron, manganese, and sulfides.

Aside from oxidizing disinfectants, oxidants such as potassium permanganate and oxygen can be used solely for their oxidation properties.

Table 3-2 Common disinfection methods

| Disinfectant Type | Primary Application |
|--|------------------------------|
| Chloramines | Potable water |
| Iodine | Potable water in emergencies |
| Bromine | Nondrinking water uses |
| Chlorine dioxide | Potable water |
| Ozone | Potable water |
| Filtration/membranes | Potable water |
| Ultrasonic/ultrasound | Nondrinking water uses |
| Ultrahigh frequency | Nondrinking water uses |
| UV/advanced oxidation processes | Potable water |
| Ionized radiation (gamma, electron beam) | Nondrinking water uses |
| Cations of heavy metals (silver) | Nondrinking water uses |
| Biocides | Nondrinking water uses |

Chlorine and Chlorine Compounds

Chlorination is by far the most common form of disinfection currently practiced in the United States. It is the only disinfectant recognized as an acceptable residual disinfectant. When properly understood and correctly operated, the chlorination process is a safe, practical, and effective way to destroy many disease-causing organisms (Figures 3-3 and 3-4).

Principle of Disinfection by Chlorination

The effectiveness of chlorination depends primarily on four factors: concentration (C), contact time (T), pH, and temperature. These factors are combined in a relationship called a CT or concentration (in milligrams per liter) multiplied by the time (in minutes) at a given pH and temperature. CTs have been established for a number of pathogens, disinfectants, and levels of inactivation achieved. (See appendix C.)

The effectiveness of chlorination is also related to the temperature of the water. At lower temperatures, bacterial kill and all chemical reactions in general tend to be slower. However, chlorine is more stable in cold water, and the residual will remain for a longer period of time, compensating to some extent for the lower rate of disinfection. Other factors being equal, all disinfection processes are more effective at higher water temperatures. As temperatures change seasonally, this relationship must be included when adjusting the chlorine dosage.

It is essential that the operator understand and use these relationships in order to obtain the most effective disinfectant. The pH of the water should be checked routinely. This is particularly important if the pH of the water is being raised during disinfection to control corrosion.

It is important to recognize that the use of chlorine as the disinfectant is only one part of the multiple barrier treatment process. In fact, the USEPA acknowledges this in the drinking water regulations under the Safe Drinking Water Act (SDWA). Of equal importance is the need for improved physical removal by sedimentation and filtration. A combination of proper disinfection and improved removal by filtration often provides the most optimum treatment sequence. Chlorination alone, for example, is not recognized as an effective means for *Cryptosporidium* inactivation (Finch 1997).

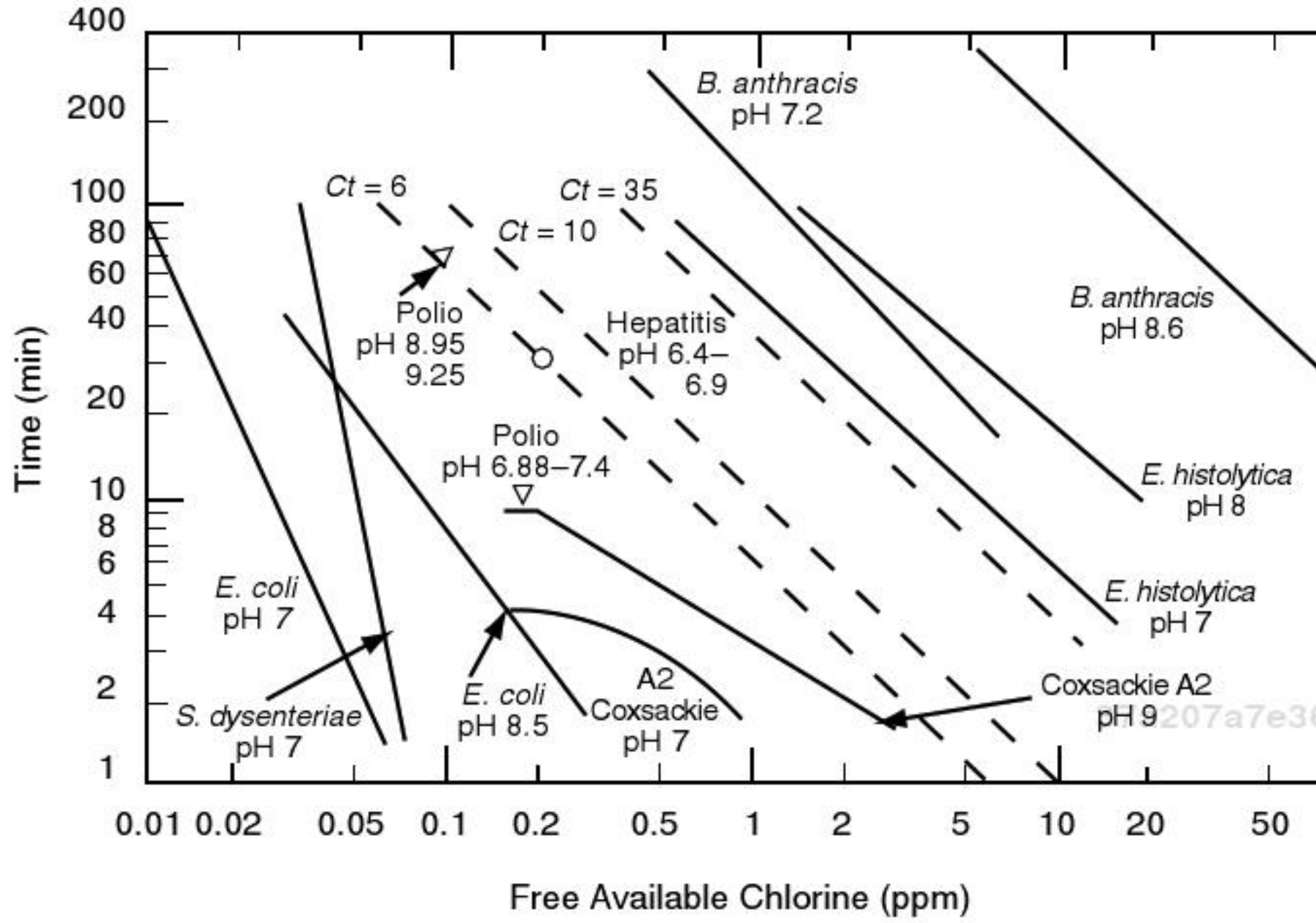
Residual disinfection. All surface waters and most groundwater systems are required to maintain a measurable residual disinfectant to guard against recontamination, control biofilms and biological growth, meet the USEPA Coliform Rule, and provide an indicator of system integrity and quality. Only chlorine and chloramines are accepted universally as residual disinfectants.

The USEPA's maximum residual disinfection levels (MRDLs) are 4 mg/L for chlorine and chloramines, and 0.8 mg/L for chlorine dioxide.

Interference Substances

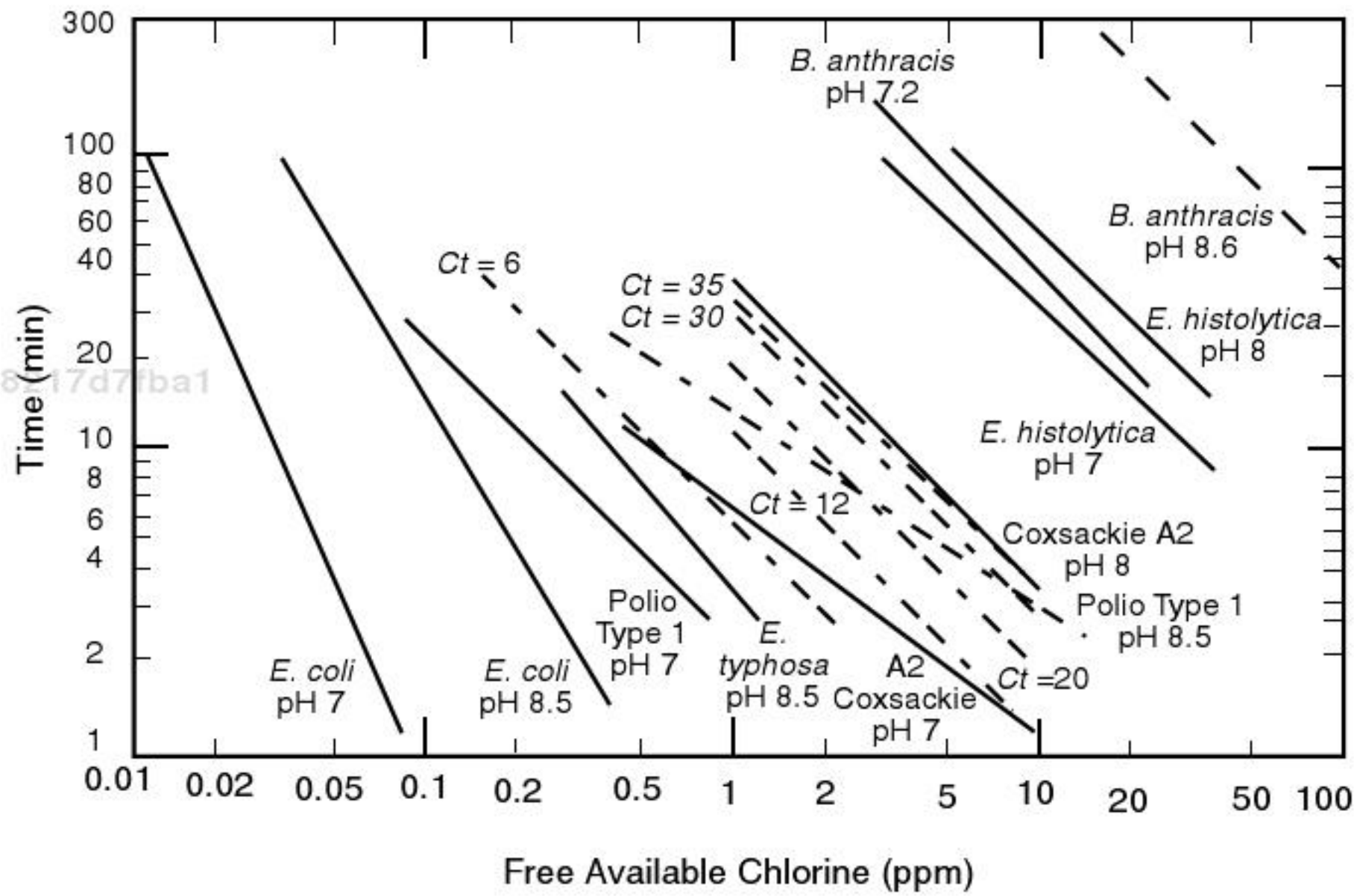
Chlorine acts as an effective disinfectant only if it comes in contact with the organisms to be killed. Turbidity, caused by tiny particles of minerals or organic matter suspended in the water, can prevent good contact and protect the pathogens from the effects of chlorine. Therefore, for chlorination to be effective, turbidity must be reduced to very low levels.

As discussed earlier, chlorine reacts with other substances in water, such as organic matter and ammonia. Because these compounds result in the formation of combined residuals, their concentrations are an important factor in determining chlorine dosages.



Source: Baumann and Ludwig, 1962.

Figure 3-3 Disinfection versus free available chlorine residuals. Time scale is for 99.6 to 100 percent kill. Temperature was in the range of 20 to 29°C, with pH as indicated.



Source: Baumann and Ludwig, 1962.

Figure 3-4 Disinfection versus free available chlorine residuals. Time scale is for 99.6 to 100 percent kill. Temperature was in the range of 0 to 5°C, with pH as indicated.

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M3000 IEC Low-voltage Induction Motors 400 V 50 Hz



ABB



Making you more Competitive

ABB LV Motors knows about customer needs. For over 100 years we have been designing motors for every need and application. With a reputation for quality that is second to none, our offering is further complemented by our 24-hour availability, unsurpassed reliability and leading technology evident in our eBusiness solutions. For top performance and high efficiency motors combined with a unique and complete service offering, customers continually choose the ABB brand. From the most demanding industries to standard applications, our customers can rest assured that their needs are being met.

M3000 M3000 Range

Sometimes needs can be highly demanding. For those occasions, it's reassuring to know you can count on the highest quality motors, customized to fit your individual needs. Our unique M3000 range offers eff1 motors for the highest efficiency levels, bringing you environmental and economical savings. Thanks to our extended support and services such as eBusiness solutions, we also provide you with easy ordering and quick delivery. And our engineering support team offers a unique opportunity to receive product consultation from the people who designed these motors especially for you.



A comprehensive range of motors

The M3000 range of motors is a comprehensive offering of motors and variants, providing add-on features and the opportunity to customize motors for specific needs.

The range includes marine motors, motors for use in hazardous areas, single-phase motors and brake motors as well as water-cooled motors and wind turbine generators.

ABB has had eff1-equivalent motors on the market for years. eff1 is a default value for the entire M3000 range.

As winners of the International Energy Agency's high-efficiency motor competition in 1999, we are also able to offer our customers premium value.

More than efficiency

M3000 motors provide many other characteristics than high efficiency. Improved bearing construction gives longer re-greasing intervals and longer bearing service life. The new motor designs improve starting characteristics and give a higher starting torque.

BusinessOnline

BusinessOnline, at <http://online.abb.com> gives you real-time, on-line access to your own personal portal to ABB motors and drives. You can choose, configure and order products, determine their availability and stock levels, follow their progress through the order-processing and delivery chains, and access a wealth of support services and technical information such as drawings, test results and technical documentation.

Motors for EU motor efficiency levels

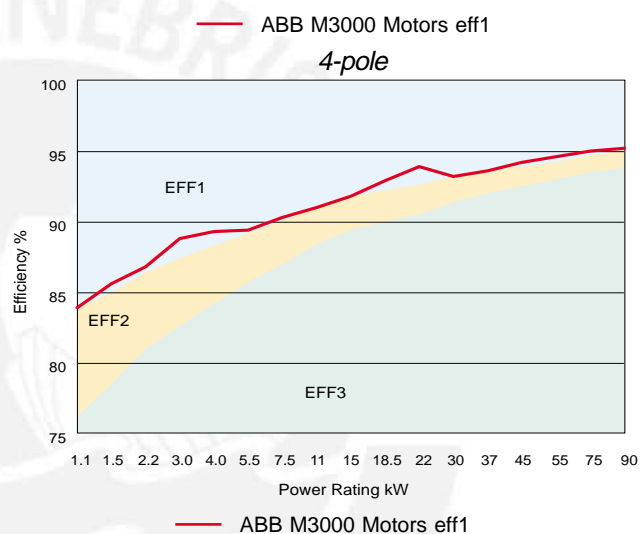
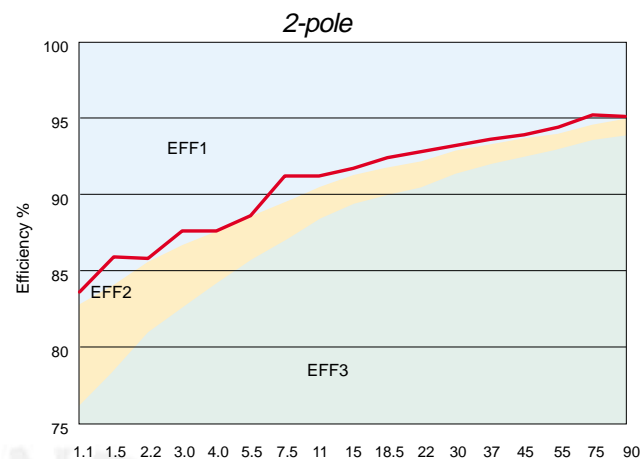
A new Europe-wide agreement will ensure that the efficiency levels of electric motors manufactured in Europe are clearly displayed. In contrast to the American legislation on motor efficiency, the European agreement does not establish mandatory efficiency levels. It basically establishes three classes, giving motor manufacturers an incentive to qualify for a higher class.

ABB is one of only a handful of leading motor manufacturers in Europe, to have a motor range to meet or exceed the minimum efficiencies stated in the highest level of the EU agreement of LV motors.

These efficiency levels apply to 2- and 4-pole, three phase squirrel cage induction motors, rated for 400V, 50Hz, with S1 duty class with the output 1.1 to 90 kW, which account for the largest volume on the market.

The efficiency of motors from different manufacturers are collated in a database, EURODEEM, published by the European Commission. It is accessible over the Internet at <http://iamest.jrc.it/projects/eem/eurodeem.htm>.

ABB M3000 three phase induction motors, 400 V 50 Hz - EU motor efficiency levels



EU efficiency classes

| Output kW | 2-pole Boarderline | | 4-pole Boarderline | |
|-----------|--------------------|-----------|--------------------|-----------|
| | EFF2/EFF3 | EFF1/EFF2 | EFF2/EFF3 | EFF1/EFF2 |
| 1.1 | 76.2 | 82.8 | 76.2 | 83.8 |
| 1.5 | 78.5 | 84.1 | 78.5 | 85.0 |
| 2.2 | 81.0 | 85.6 | 81.0 | 86.4 |
| 3 | 82.6 | 86.7 | 82.6 | 87.4 |
| 4 | 84.2 | 87.6 | 84.2 | 88.3 |
| 5.5 | 85.7 | 88.6 | 85.7 | 89.2 |
| 7.5 | 87.0 | 89.5 | 87.0 | 90.1 |
| 11 | 88.4 | 90.5 | 88.4 | 91.0 |
| 15 | 89.4 | 91.3 | 89.4 | 91.8 |
| 18.5 | 90.0 | 91.8 | 90.0 | 92.2 |
| 22 | 90.5 | 92.2 | 90.5 | 92.6 |
| 30 | 91.4 | 92.9 | 91.4 | 93.2 |
| 37 | 92.0 | 93.3 | 92.0 | 93.6 |
| 45 | 92.5 | 93.7 | 92.5 | 93.9 |
| 55 | 93.0 | 94.0 | 93.0 | 94.2 |
| 75 | 93.6 | 94.6 | 93.6 | 94.7 |
| 90 | 93.9 | 95.0 | 93.9 | 95.0 |

Technical features

Electrical protection

Thermistors (PTC) are fitted as a standard or as option to the windings of motors to protect against overheating.

Voltage ranges for extra versatility

A wide range of voltages up to max. 690 V for 50 and 60 Hz available.

Reliable windings

To ensure long lifetime, the winding is made from the latest available material in class F protection and temperature rise limited to class B (80 K) in standard motors.

Strong corrosion protection

The motors are made to withstand aggressive environments. They have strong and effective protection against corrosion.

Bearings with high load capacity

All motors are provided with deep-groove ball bearings as standard and they are designed for long lifetime. For motors with regreasing possibility, the lifetime is extended. Aluminium motors in sizes 63-180 and cast iron motors in sizes 71-132 are greased for life. Aluminium motors in sizes 200-250, cast iron motors in sizes 160-400 and all steel motors have a regreasing device as a standard.

Low noise level

An important objective in our design work is to minimize the noise level. And we have been successful.

Mechanical design

Aluminium motors, totally enclosed fan cooled IP 55

Basic design manufactured from pressure die-cast corrosion resistant light alloy with a very low copper content. The flange bearing shields of sizes 180 to 250 are made of cast iron. Sizes 200-250 have steel feet, bolted to the stator frame. Sizes 112 to 250 have drain holes and plugs as standard. See catalogue BA/M2AA GB for details.

The end shields are made from cast iron. Drain holes and plugs as standard. This construction offers efficient motors with a lighter weight.

See catalogue BA/M2CA GB for details.

Steel motors, totally enclosed fan cooled IP 55

Basic design manufactured from profile-pressed steel sheet. The stator core is welded into the stator frame and contributes to its excellent mechanical properties.

Cast iron motors, totally enclosed fan cooled IP 55

Heavy duty design, manufactured from extra corrosion resistant cast iron materials to be used in all kind of environment. The motor is mechanically very strong and robust and as standard designed for additional energy saving through frequency converter drives. Drain holes and plugs as standard in sizes 180 to 400.

See catalogue BA/M2BA GB for details.

Motors for other voltages

Motors wound for a given voltage at 50 Hz can also be used for other voltages. Recalculation factors for current and torque

values are given below; efficiency, power factor and speed remain approximately the same.

Guaranteed values available on request.

| Motor wound for | 230V | | 400V | | 500V | | 690 V | |
|----------------------------|------|------|------|------|------|------|-------|------|
| Connected to 50 Hz | 220V | 230V | 380V | 415V | 500V | 550V | 660V | 690V |
| % of values at 400V, 50 Hz | | | | | | | | |
| Output | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| I_N | 182 | 174 | 105 | 98 | 80 | 75 | 61 | 58 |
| I_S/I_N | 90 | 100 | 90 | 106 | 100 | 119 | 90 | 100 |
| T_S/T_N | 90 | 100 | 90 | 106 | 100 | 119 | 90 | 100 |
| T_{max}/T_N | 90 | 100 | 90 | 106 | 100 | 119 | 90 | 100 |

ABB reserves the right to change the design, technical specification and dimensions without prior notice.

Technical data

Three phase motors, cast iron frame



IP 55, IC 411; Insulation class F, temperature rise class B

| Output kW | De- sign | Type designation | Product code | Speed r/min | Efficiency | | Power factor cos φ | Current | | Torque | | | Moment of inertia J=1/4 GD ² kgm ² | Weight kg | Sound pressure level LP dB(A) |
|-----------------------------|---------------|-------------------------------|------------------|----------------|----------------------|--------------------|--------------------------|----------------|----------------------------------|----------------|----------------------------------|------------------------------------|---|--------------|--|
| | | | | | Full load 100% | 3/4 load 75% | | I _N | I _s I _N | T _N | T _s T _N | T _{max} T _N | | | |
| 3000 r/min = 2 poles | | | | | | | | | | | | | | | |
| 400 V 50 Hz | | | | | | | | | | | | | | | |
| 0.37 | | M2BA 71 M2 A | 3GBA 071 310-••C | 2810 | 71.0 | 68.1 | 0.80 | 0.94 | 6.1 | 1.26 | 2.2 | 2.2 | 0.0003 | 10 | 56 |
| 0.55 | | M2BA 71 M2 B | 3GBA 071 320-••C | 2800 | 74.0 | 71.4 | 0.82 | 1.31 | 6.1 | 1.88 | 2.2 | 2.2 | 0.0004 | 11 | 56 |
| 0.75 | | M2BA 80 M2 A | 3GBA 081 310-••C | 2850 | 77.2 | 75.5 | 0.86 | 1.63 | 6.1 | 2.51 | 2.2 | 2.2 | 0.0009 | 16 | 57 |
| 1.1 | ²⁾ | M2BA 80 M2 B | 3GBA 081 320-••C | 2850 | 80.2 | 77.6 | 0.85 | 2.33 | 7.0 | 3.69 | 2.2 | 2.2 | 0.0011 | 17 | 58 |
| 1.5 | ²⁾ | M2BA 90 S2 A | 3GBA 091 110-••C | 2850 | 81.6 | 79.0 | 0.85 | 3.13 | 7.0 | 5.03 | 2.2 | 2.2 | 0.0014 | 21 | 61 |
| 2.2 | ²⁾ | M2BA 90 L2 A | 3GBA 091 510-••C | 2850 | 84.2 | 81.9 | 0.84 | 4.49 | 7.0 | 7.37 | 2.2 | 2.2 | 0.0016 | 24 | 61 |
| 3 | ²⁾ | M2BA 100 L2 A | 3GBA 101 510-••C | 2870 | 85.1 | 83.2 | 0.86 | 5.92 | 7.0 | 9.98 | 2.2 | 2.2 | 0.004 | 33 | 65 |
| 4 | ²⁾ | M2BA 112 M2 A | 3GBA 111 310-••C | 2900 | 86.0 | 84.5 | 0.89 | 7.52 | 7.0 | 13.17 | 2.2 | 2.2 | 0.0067 | 42 | 67 |
| 5.5 | ²⁾ | M2BA 132 S2 A | 3GBA 131 110-••C | 2920 | 88.6 | 88.1 | 0.88 | 10.19 | 7.0 | 17.99 | 2.2 | 2.2 | 0.0124 | 58 | 70 |
| 7.5 | ²⁾ | M2BA 132 S2 B | 3GBA 131 120-••C | 2920 | 89.9 | 88.7 | 0.89 | 13.54 | 7.0 | 24.53 | 2.2 | 2.2 | 0.0149 | 63 | 70 |
| 11 | | M3BP 160 MA | 3GBP 161 101-••A | 2930 | 91.2 | 91.2 | 0.88 | 20 | 6.3 | 36 | 1.9 | 2.5 | 0.039 | 105 | 69 |
| 15 | | M3BP 160 M | 3GBP 161 102-••A | 2920 | 91.7 | 91.7 | 0.90 | 27 | 6.6 | 49 | 2.3 | 2.5 | 0.047 | 118 | 69 |
| 18.5 | | M3BP 160 L | 3GBP 161 103-••A | 2920 | 92.4 | 92.4 | 0.91 | 32 | 7.3 | 60 | 2.6 | 2.7 | 0.053 | 133 | 69 |
| 22 | ³⁾ | HO ⁴⁾ M3BP 160 LB | 3GBP 161 104-••A | 2920 | 92.1 | 92.1 | 0.91 | 38 | 7.1 | 72 | 2.6 | 2.6 | 0.058 | 140 | 69 |
| 22 | | M3BP 180 M | 3GBP 181 101-••A | 2930 | 92.8 | 92.8 | 0.89 | 39 | 7.2 | 71 | 2.5 | 2.7 | 0.077 | 178 | 69 |
| 30 | ³⁾ | HO ⁴⁾ M3BP 180 LB | 3GBP 181 102-••A | 2945 | 93.7 | 93.7 | 0.89 | 53 | 8.3 | 97 | 3.1 | 3.4 | 0.092 | 194 | 70 |
| 30 | | M3BP 200 MLA | 3GBP 201 001-••A | 2955 | 93.2 | 93.2 | 0.88 | 53 | 7.3 | 97 | 2.4 | 3.1 | 0.15 | 250 | 72 |
| 37 | | M3BP 200 MLB | 3GBP 201 002-••A | 2950 | 93.6 | 93.6 | 0.89 | 64 | 7.3 | 120 | 2.5 | 3.2 | 0.18 | 270 | 72 |
| 45 | | HO ⁴⁾ M3BP 200 MLC | 3GBP 201 003-••A | 2950 | 93.8 | 93.8 | 0.89 | 78 | 7.3 | 146 | 2.6 | 3.3 | 0.19 | 280 | 72 |
| 45 | | M3BP 225 SMB | 3GBP 221 001-••A | 2960 | 93.9 | 93.9 | 0.88 | 79 | 7.3 | 145 | 2.5 | 2.8 | 0.26 | 335 | 74 |
| 55 | | HO ⁴⁾ M3BP 225 SMC | 3GBP 221 002-••A | 2960 | 94.3 | 94.3 | 0.89 | 95 | 7.0 | 177 | 2.5 | 2.9 | 0.29 | 355 | 74 |
| 55 | | M3BP 250 SMA | 3GBP 251 001-••A | 2970 | 94.4 | 94.4 | 0.89 | 95 | 7.5 | 177 | 2.0 | 3.0 | 0.49 | 420 | 75 |
| 75 | | HO ⁴⁾ M3BP 250 SMB | 3GBP 251 002-••A | 2970 | 95.2 | 95.2 | 0.90 | 127 | 7.3 | 241 | 2.1 | 3.0 | 0.57 | 465 | 75 |
| 75 | | M3BP 280 SMA | 3GBP 281 210-••G | 2978 | 94.8 | 94.3 | 0.88 | 131 | 7.6 | 240 | 2.1 | 3.0 | 0.8 | 625 | 77 |
| 90 | | M3BP 280 SMB | 3GBP 281 220-••G | 2976 | 95.1 | 94.8 | 0.90 | 152 | 7.4 | 289 | 2.1 | 2.9 | 0.9 | 665 | 77 |
| 110 | | HO ⁴⁾ M3BP 280 SMC | 3GBP 281 230-••G | 2978 | 95.7 | 95.3 | 0.90 | 185 | 7.9 | 353 | 2.4 | 3.0 | 1.15 | 725 | 77 |
| 110 | | M3BP 315 SMA | 3GBP 311 210-••G | 2982 | 95.1 | 94.4 | 0.86 | 194 | 7.6 | 352 | 2.0 | 3.0 | 1.2 | 880 | 78 |
| 132 | | M3BP 315 SMB | 3GBP 311 220-••G | 2982 | 95.4 | 94.9 | 0.88 | 228 | 7.4 | 423 | 2.2 | 3.0 | 1.4 | 940 | 78 |
| 160 | | M3BP 315 SMC | 3GBP 311 230-••G | 2981 | 96.1 | 95.6 | 0.89 | 269 | 7.5 | 513 | 2.3 | 3.0 | 1.7 | 1025 | 78 |
| 200 | | M3BP 315 MLA | 3GBP 311 410-••G | 2980 | 96.3 | 95.9 | 0.90 | 336 | 7.7 | 641 | 2.6 | 3.0 | 2.1 | 1190 | 78 |
| 250 | | M2BA 355 S | 3GBA 351 100-••A | 2980 | 96.1 | 95.7 | 0.92 | 410 | 6.6 | 801 | 1.3 | 3.0 | 3.8 | 1550 | 83 |
| 315 | | M2BA 355 SMA | 3GBA 351 210-••A | 2978 | 96.6 | 96.4 | 0.92 | 510 | 7.7 | 1010 | 1.3 | 3.3 | 4.8 | 1750 | 83 |
| 355 | ³⁾ | M2BA 355 SMB | 3GBA 351 220-••A | 2975 | 96.4 | 96.2 | 0.92 | 580 | 7.1 | 1140 | 1.2 | 3.2 | 4.8 | 1750 | 83 |
| 400 | | M2BA 355 MLA | 3GBA 351 410-••A | 2982 | 96.6 | 96.4 | 0.92 | 655 | 7.7 | 1281 | 1.6 | 3.3 | 6 | 2150 | 83 |
| 400 | | M2BA 400 M | 3GBA 401 300-••A | 2982 | 96.6 | 96.4 | 0.92 | 655 | 7.7 | 1281 | 1.6 | 3.3 | 6 | 2200 | 83 |
| 450 | ³⁾ | M2BA 355 MLC | 3GBA 351 430-••A | 2977 | 96.6 | 96.4 | 0.92 | 730 | 7.8 | 1444 | 1.2 | 3.2 | 6 | 2150 | 83 |
| 450 | ³⁾ | M2BA 400 MA | 3GBA 401 310-••A | 2977 | 96.6 | 96.4 | 0.92 | 730 | 7.8 | 1444 | 1.2 | 3.2 | 6 | 2200 | 83 |
| 500 | ³⁾ | M2BA 400 LKA | 3GBA 401 510-••A | 2980 | 96.6 | 96.5 | 0.93 | 795 | 7.0 | 1602 | 0.8 | 2.8 | 7.5 | 2850 | 85 |
| 560 | ³⁾ | M2BA 400 LKB | 3GBA 401 520-••A | 2983 | 96.7 | 96.5 | 0.92 | 910 | 7.3 | 1793 | 0.7 | 3.4 | 8.5 | 2900 | 85 |

²⁾ Efficiency class eff2.

³⁾ Temperature rise class F

⁴⁾ High output design (Cenelec +1, 2, 3)

During the transition period some motor types belonging to M3000 range still have the old product codes and type designations. Always check the valid code before ordering.

Efficiency classes fixed for ranges 1.1 to 90 kW, see page 4 (available only by 2- and 4-poles).

Technical data

Three phase motors, cast iron frame

IP 55, IC 411; Insulation class F, temperature rise class B

| Output kW | De-sign | Type designation | Product code | Speed r/min | Efficiency | | Power factor cos φ | Current | | Torque | | | Moment of inertia J=1/4 GD ² kgm ² | Weight kg | Sound pressure level LP dB(A) |
|-----------------------------|---------------|-------------------------------|-------------------|-------------|----------------|--------------|--------------------|------------------|--------------------------------|-------------------|--------------------------------|----------------------------------|--|-----------|-------------------------------|
| | | | | | Full load 100% | 3/4 load 75% | | I _N A | I _s /I _N | T _N Nm | T _s /T _N | T _{max} /T _N | | | |
| 1000 r/min = 6 poles | | | | | | | | | | | | | | | |
| 400 V 50 Hz | | | | | | | | | | | | | | | |
| 0.18 | | M2BA 71 M6 A | 3GBA 073 310-...C | 880 | 57.0 | 50.4 | 0.63 | 0.73 | 4.0 | 1.95 | 1.7 | 1.8 | 0.0006 | 10 | 42 |
| 0.25 | | M2BA 71 M6 B | 3GBA 073 320-...C | 880 | 61.5 | 58.3 | 0.65 | 0.91 | 4.0 | 2.71 | 1.7 | 1.8 | 0.0007 | 11 | 42 |
| 0.37 | | M2BA 80 M6 A | 3GBA 083 310-...C | 920 | 68.0 | 63.2 | 0.65 | 1.21 | 5.0 | 3.84 | 1.7 | 1.8 | 0.0016 | 17 | 45 |
| 0.55 | | M2BA 80 M6 B | 3GBA 083 320-...C | 920 | 70.0 | 65.1 | 0.66 | 1.72 | 5.0 | 5.71 | 1.7 | 1.8 | 0.002 | 18 | 45 |
| 0.75 | | M2BA 90 S6 A | 3GBA 093 110-...C | 920 | 74.0 | 70.2 | 0.71 | 2.08 | 5.0 | 7.79 | 2.0 | 2.2 | 0.0029 | 21 | 48 |
| 1.1 | | M2BA 90 L6 A | 3GBA 093 510-...C | 920 | 75.0 | 73.1 | 0.73 | 2.9 | 5.0 | 11.42 | 2.0 | 2.2 | 0.0038 | 25 | 48 |
| 1.5 | | M2BA 100 L6 A | 3GBA 103 510-...C | 930 | 79.0 | 75.5 | 0.73 | 3.76 | 5.5 | 15.4 | 2.0 | 2.2 | 0.01 | 32 | 51 |
| 2.2 | | M2BA 112 M6 A | 3GBA 113 310-...C | 940 | 83.0 | 81.1 | 0.73 | 5.24 | 5.5 | 22.35 | 2.0 | 2.2 | 0.0156 | 40 | 54 |
| 3 | | M2BA 132 S6 A | 3GBA 133 110-...C | 960 | 84.5 | 82.4 | 0.77 | 6.67 | 6.5 | 29.84 | 2.0 | 2.2 | 0.0312 | 55 | 56 |
| 4 | | M2BA 132 M6 A | 3GBA 133 310-...C | 960 | 85.0 | 84.1 | 0.76 | 8.94 | 6.5 | 39.79 | 2.0 | 2.2 | 0.0407 | 65 | 56 |
| 5.5 | | M2BA 132 M6 B | 3GBA 133 320-...C | 950 | 87.0 | 85.9 | 0.78 | 11.7 | 6.5 | 55 | 2.0 | 2.2 | 0.0533 | 75 | 56 |
| 7.5 | | M3BP 160 M | 3GBP 163 101-...A | 970 | 89.3 | 89.3 | 0.79 | 15.4 | 6.7 | 74 | 2.0 | 2.8 | 0.089 | 115 | 59 |
| 11 | | M3BP 160 L | 3GBP 163 102-...A | 970 | 89.8 | 89.8 | 0.78 | 23 | 7.1 | 109 | 2.2 | 2.9 | 0.107 | 135 | 59 |
| 14 | ³⁾ | HO ⁴⁾ M3BP 160 LB | 3GBP 163 103-...A | 960 | 89.1 | 89.1 | 0.77 | 29.5 | 7.6 | 139 | 2.7 | 3.1 | 0.127 | 148 | 62 |
| 15 | | M3BP 180 L | 3GBP 183 101-...A | 970 | 90.8 | 90.8 | 0.78 | 31 | 7.0 | 148 | 2.1 | 3.0 | 0.217 | 177 | 59 |
| 18.5 | ³⁾ | HO ⁴⁾ M3BP 180 LB | 3GBP 183 102-...A | 965 | 90.6 | 90.6 | 0.79 | 37.5 | 6.2 | 183 | 2.0 | 2.6 | 0.237 | 185 | 59 |
| 18.5 | | M3BP 200 MLA | 3GBP 203 001-...A | 985 | 91.1 | 91.1 | 0.81 | 36 | 7.0 | 179 | 2.5 | 2.7 | 0.37 | 245 | 63 |
| 22 | | M3BP 200 MLB | 3GBP 203 002-...A | 980 | 91.7 | 91.7 | 0.81 | 43 | 7.2 | 214 | 2.5 | 2.7 | 0.43 | 260 | 63 |
| 30 | | HO ⁴⁾ M3BP 200 MLC | 3GBP 203 003-...A | 980 | 91.7 | 91.7 | 0.81 | 56 | 7.5 | 292 | 3.3 | 3.0 | 0.49 | 275 | 63 |
| 30 | | M3BP 225 SMB | 3GBP 223 001-...A | 985 | 92.8 | 92.8 | 0.83 | 56 | 6.6 | 291 | 2.5 | 2.7 | 0.64 | 320 | 63 |
| 37 | | HO ⁴⁾ M3BP 225 SMC | 3GBP 223 002-...A | 985 | 93.2 | 93.2 | 0.83 | 69 | 7.7 | 359 | 3.1 | 3.0 | 0.75 | 345 | 63 |
| 37 | | M3BP 250 SMA | 3GBP 253 001-...A | 985 | 93.7 | 93.7 | 0.83 | 69 | 7.3 | 359 | 2.8 | 2.8 | 1.16 | 415 | 63 |
| 45 | | HO ⁴⁾ M3BP 250 SMB | 3GBP 253 002-...A | 985 | 94.1 | 94.1 | 0.84 | 82 | 7.3 | 436 | 2.8 | 2.8 | 1.49 | 460 | 63 |
| 45 | | M3BP 280 SMA | 3GBP 283 210-...G | 990 | 94.4 | 94.3 | 0.84 | 82 | 7.0 | 434 | 2.5 | 2.5 | 1.85 | 570 | 66 |
| 55 | | M3BP 280 SMB | 3GBP 283 220-...G | 990 | 94.6 | 94.6 | 0.84 | 101 | 7.0 | 531 | 2.7 | 2.6 | 2.2 | 610 | 66 |
| 75 | | HO ⁴⁾ M3BP 280 SMC | 3GBP 283 230-...G | 990 | 95.1 | 95.2 | 0.84 | 137 | 7.3 | 723 | 2.8 | 2.7 | 2.85 | 690 | 66 |
| 75 | | M3BP 315 SMA | 3GBP 313 210-...G | 992 | 95.0 | 94.7 | 0.82 | 141 | 7.4 | 722 | 2.4 | 2.8 | 3.2 | 830 | 70 |
| 90 | | M3BP 315 SMB | 3GBP 313 220-...G | 992 | 95.5 | 95.3 | 0.84 | 163 | 7.5 | 866 | 2.4 | 2.8 | 4.1 | 930 | 70 |
| 110 | | M3BP 315 SMC | 3GBP 313 230-...G | 991 | 95.6 | 95.5 | 0.83 | 202 | 7.4 | 1060 | 2.5 | 2.9 | 4.9 | 1000 | 70 |
| 132 | | M3BP 315 MLA | 3GBP 313 410-...G | 991 | 95.8 | 95.7 | 0.83 | 240 | 7.5 | 1272 | 2.7 | 3.0 | 5.8 | 1150 | 68 |
| 160 | | M2BA 355 S | 3GBA 353 100-...A | 992 | 95.9 | 95.7 | 0.85 | 280 | 6.8 | 1540 | 1.8 | 2.7 | 10.4 | 1550 | 75 |
| 200 | | M2BA 355 SMA | 3GBA 353 210-...A | 992 | 95.9 | 95.7 | 0.85 | 355 | 7.1 | 1925 | 2.0 | 2.7 | 12.5 | 1800 | 75 |
| 250 | | M2BA 355 SMB | 3GBA 353 220-...A | 992 | 96.0 | 95.8 | 0.84 | 450 | 7.5 | 2407 | 2.2 | 2.8 | 12.5 | 1800 | 75 |
| 250 | | M2BA 400 M | 3GBA 403 300-...A | 992 | 96.0 | 95.8 | 0.84 | 450 | 7.5 | 2407 | 2.2 | 2.8 | 12.5 | 2000 | 75 |
| 315 | | M2BA 355 MLA | 3GBA 353 410-...A | 991 | 96.2 | 96.1 | 0.84 | 565 | 7.3 | 3036 | 2.0 | 3.0 | 14.6 | 2100 | 75 |
| 315 | | M2BA 400 MA | 3GBA 403 310-...A | 991 | 96.2 | 96.1 | 0.84 | 565 | 7.3 | 3036 | 2.0 | 3.0 | 14.6 | 2150 | 75 |
| 355 | | M2BA 355 MLC | 3GBA 353 430-...A | 991 | 96.4 | 96.3 | 0.84 | 635 | 7.6 | 3421 | 1.5 | 3.0 | 15.8 | 2100 | 78 |
| 355 | | M2BA 400 MB | 3GBA 403 320-...A | 991 | 96.4 | 96.3 | 0.84 | 635 | 7.6 | 3421 | 1.5 | 3.0 | 15.8 | 2150 | 78 |
| 400 | | M2BA 400 LKA | 3GBA 403 510-...A | 992 | 96.5 | 96.4 | 0.85 | 700 | 6.4 | 3851 | 1.2 | 2.7 | 16.5 | 2800 | 80 |
| 450 | | M2BA 400 LKB | 3GBA 403 520-...A | 993 | 96.5 | 96.4 | 0.85 | 790 | 6.8 | 4328 | 1.3 | 2.8 | 19 | 3050 | 80 |
| 500 | ³⁾ | M2BA 400 LKC | 3GBA 403 530-...A | 992 | 96.5 | 96.4 | 0.85 | 880 | 6.8 | 4813 | 1.3 | 2.8 | 19 | 3050 | 80 |

³⁾ Temperature rise class F

⁴⁾ High output design (Cenelec +1, 2, 3)

Efficiency classes fixed for ranges 1.1 to 90 kW, see page 4 (available only by 2- and 4-poles).

During the transition period some motor types belonging to M3000 range still have the old product codes and type designations. Always check the valid code before ordering.

Technical data

Three phase motors, cast iron frame

IP 55, IC 411; Insulation class F, temperature rise class B

| Output kW | De- sign | Type designation | Product code | Speed r/min | Efficiency | | Power factor cos φ | Current | | Torque | | | Moment of inertia J=1/4 GD ² kgm ² | Weight kg | Sound pressure level LP dB(A) |
|----------------------------|---------------|-------------------------------|-------------------|----------------|----------------------|--------------------|--------------------------|---------------------|----------------------------------|----------------------|----------------------------------|------------------------------------|---|--------------|--|
| | | | | | Full load 100% | 3/4 load 75% | | I _N A | I _s I _N | T _N Nm | T _s T _N | T _{max} T _N | | | |
| 750 r/min = 8 poles | | | | | | | | | | | | | | | |
| 400 V 50 Hz | | | | | | | | | | | | | | | |
| 4 | | M3BP 160 MA | 3GBP 164 101-***A | 715 | 84.1 | 84.7 | 0.69 | 10 | 5.2 | 54 | 2.1 | 2.4 | 0.072 | 100 | 59 |
| 5.5 | | M3BP 160 M | 3GBP 164 102-***A | 710 | 84.7 | 85.5 | 0.70 | 13.4 | 5.4 | 74 | 2.4 | 2.6 | 0.091 | 113 | 59 |
| 7.5 | | M3BP 160 L | 3GBP 164 103-***A | 715 | 86.3 | 87.2 | 0.70 | 18.1 | 5.4 | 100 | 2.4 | 2.8 | 0.131 | 126 | 59 |
| 8.5 | ³⁾ | HO ⁴⁾ M3BP 160 LB | 3GBP 164 104-***A | 700 | 83.5 | 85.0 | 0.70 | 21 | 5.1 | 115 | 2.4 | 2.5 | 0.131 | 128 | 62 |
| 11 | | M3BP 180 L | 3GBP 184 101-***A | 720 | 88.7 | 89.2 | 0.76 | 23.5 | 5.9 | 146 | 2.4 | 2.6 | 0.224 | 177 | 59 |
| 15 | ³⁾ | HO ⁴⁾ M3BP 180 LB | 3GBP 184 102-***A | 720 | 88.0 | 89.2 | 0.76 | 32.5 | 6.0 | 199 | 2.5 | 2.6 | 0.24 | 185 | 62 |
| 15 | | M3BP 200 MLA | 3GBP 204 001-***A | 740 | 91.1 | 91.1 | 0.82 | 29 | 7.4 | 194 | 1.8 | 3.0 | 0.45 | 250 | 60 |
| 18.5 | | HO ⁴⁾ M3BP 200 MLB | 3GBP 204 002-***A | 735 | 91.4 | 91.4 | 0.81 | 36 | 6.7 | 237 | 1.7 | 2.8 | 0.54 | 275 | 60 |
| 18.5 | | M3BP 225 SMA | 3GBP 224 001-***A | 730 | 91.1 | 91.1 | 0.79 | 37 | 6.2 | 242 | 1.9 | 2.7 | 0.61 | 305 | 63 |
| 22 | | M3BP 225 SMB | 3GBP 224 002-***A | 730 | 91.5 | 91.5 | 0.77 | 45 | 6.0 | 288 | 1.9 | 2.7 | 0.68 | 320 | 63 |
| 30 | | HO ⁴⁾ M3BP 225 SMC | 3GBP 224 003-***A | 735 | 91.8 | 91.8 | 0.79 | 60 | 7.2 | 390 | 2.1 | 3.3 | 0.8 | 345 | 63 |
| 30 | | M3BP 250 SMA | 3GBP 254 001-***A | 735 | 92.8 | 92.8 | 0.79 | 59 | 6.9 | 390 | 1.9 | 2.9 | 1.25 | 415 | 63 |
| 37 | | HO ⁴⁾ M3BP 250 SMB | 3GBP 254 002-***A | 735 | 93.2 | 93.2 | 0.81 | 71 | 7.2 | 481 | 2.0 | 2.9 | 1.52 | 460 | 63 |
| 37 | | M3BP 280 SMA | 3GBP 284 210-***G | 741 | 93.4 | 93.0 | 0.78 | 74 | 7.3 | 477 | 1.7 | 3.0 | 1.85 | 605 | 65 |
| 45 | | M3BP 280 SMB | 3GBP 284 220-***G | 741 | 94.0 | 94.0 | 0.78 | 90 | 7.6 | 580 | 1.8 | 3.1 | 2.2 | 645 | 65 |
| 55 | | HO ⁴⁾ M3BP 280 SMC | 3GBP 284 230-***G | 741 | 94.4 | 94.0 | 0.80 | 105 | 7.9 | 709 | 1.9 | 3.1 | 2.85 | 725 | 65 |
| 55 | | M3BP 315 SMA | 3GBP 314 210-***G | 742 | 94.1 | 94.0 | 0.81 | 104 | 7.1 | 708 | 1.6 | 2.7 | 3.2 | 830 | 62 |
| 75 | | M3BP 315 SMB | 3GBP 314 220-***G | 741 | 94.4 | 94.3 | 0.82 | 141 | 7.1 | 968 | 1.7 | 2.7 | 4.1 | 930 | 62 |
| 90 | | M3BP 315 SMC | 3GBP 314 230-***G | 741 | 94.8 | 94.7 | 0.82 | 167 | 7.4 | 1161 | 1.8 | 2.7 | 4.9 | 1000 | 64 |
| 110 | | M3BP 315 MLA | 3GBP 314 410-***G | 740 | 95.0 | 95.0 | 0.83 | 203 | 7.3 | 1420 | 1.8 | 2.7 | 5.8 | 1150 | 72 |
| 132 | | M2BA 355 S | 3GBA 354 100-***A | 742 | 95.0 | 94.9 | 0.80 | 250 | 5.8 | 1699 | 1.5 | 2.3 | 10.4 | 1550 | 75 |
| 160 | | M2BA 355 SMA | 3GBA 354 210-***A | 742 | 95.2 | 95.1 | 0.80 | 305 | 6.3 | 2059 | 1.7 | 2.4 | 12.5 | 1800 | 75 |
| 200 | | M2BA 355 MLA | 3GBA 354 410-***A | 743 | 95.5 | 95.1 | 0.77 | 395 | 6.6 | 2571 | 1.8 | 2.7 | 14.6 | 2100 | 75 |
| 200 | | M2BA 400 M | 3GBA 404 300-***A | 743 | 95.5 | 95.1 | 0.77 | 395 | 6.6 | 2571 | 1.8 | 2.7 | 14.6 | 2150 | 75 |
| 250 | | M2BA 355 MLC | 3GBA 354 430-***A | 744 | 95.7 | 95.4 | 0.80 | 470 | 6.6 | 3209 | 1.5 | 3.0 | 15.8 | 2100 | 75 |
| 250 | | M2BA 400 MA | 3GBA 404 310-***A | 744 | 95.7 | 95.4 | 0.80 | 470 | 6.6 | 3209 | 1.5 | 3.0 | 15.8 | 2150 | 75 |
| 315 | | M2BA 400 LKA | 3GBA 404 510-***A | 744 | 96.0 | 95.9 | 0.79 | 605 | 6.3 | 4043 | 1.4 | 2.6 | 16.5 | 2800 | 80 |
| 355 | | M2BA 400 LKB | 3GBA 404 520-***A | 744 | 96.2 | 96.0 | 0.79 | 680 | 6.6 | 4557 | 1.5 | 2.7 | 19 | 3050 | 80 |

³⁾ Temperature rise class F

⁴⁾ High output design (Cenelec +1, 2, 3)

Efficiency classes fixed for ranges 1.1 to 90 kW, see page 4 (available only by 2- and 4-poles).

During the transition period some motor types belonging to M3000 range still have the old product codes and type designations. Always check the valid code before ordering.

Products



Standard

eff1 motors are an energy-saving solution for all demanding applications. Reliability and a long service life ensure the lowest life-cycle costs. Standard motors are always in stock, and VSD is standard. Available in aluminium, cast iron and steel frames, and in many variants. Can be customized to meet special requirements.

Motors for hazardous areas

Our M3000 Ex-motors are designed to meet the demanding requirements of the oil, gas and petrochemical industries for high efficiency, optimized electrical and mechanical performance and excellent availability.

Three types of Ex-motor are available: flameproof (EEx d and EEx de) in a cast iron frame, and increased safety (EEx e) and non-sparking (EEx nA), both of which come in either an aluminium or cast iron frame. The motors fulfill most industry specifications as standard and have high efficiency levels corresponding to the European eff1 standard. Ex-motors are engineered to save energy and give the lowest life-cycle costs.

Premium efficiency

There are instances when even EU efficiency class eff1 is not enough. Such as whenever the stringent requirements of the North American market, EPCA, have to be met.

Brake

M3000 brake motors are designed to run at peak performance in order to ensure energy savings and lower operating costs during the motor's lifetime.

Marine

M3000 marine motors are certified according to all the major international classification societies. They are available in a wide choice of variants in three frame materials: aluminium, steel and cast iron to IP 55 or IP 23 (open drip proof) standard. Onboard ship, the economical use of energy is really important. M3000 marine motors are designed to save energy.

And many, many more

You will always find the right motor for your application in our extensive range of M3000 motors. Single-phase, roller table, water-cooled, wind turbine generators – we can offer you a motor with excellent performance characteristics and availability, and a global service to go with it. Our open drip proof IP 23 motors combine light weight with optimized performance, and our smoke venting motors are certified to withstand temperatures of 250°C for 2 hours. We have high-speed motors, slip-ring motors, traction motors and motors equipped with a holding brake. These are complemented by rotor and stator units.



Catalogues and brochures for these motors are available from:

ABB Motors
Marketing communications
P.O.Box 633
FIN-65101 Vaasa
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www.abb.com/motors&drives

LV Motor

Manufacturing sites (*) and some of the biggest sales companies.

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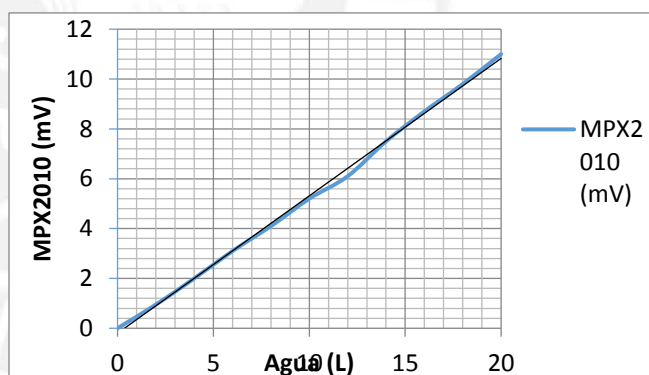
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ANEXO 3:

Medición de Nivel en un Tanque usando presión de aire en una manguera

Para medir el nivel de líquido en los dos tanques con sensores de presión, se usó el siguiente método: Se adaptó una manguera en la base del recipiente, como si de un indicador visual se tratase. Luego, se colocó al final de la manguera el sensor de presión respectivo a cada tanque (50 kPa para el tanque de 20000 litros, 10 kPa para el tanque de 20 litros), procurando que la manguera sea más alta que el tanque para asegurar que el sensor no se moje. Entonces, cuando se encuentra presente un cierto nivel de líquido en el tanque, este líquido ingresa también a la manguera, presionando el aire que queda en ella contra el sensor de presión, generando una medida por parte de este último. Cabe resaltar que, debido a que el final de la manguera está cerrado, el nivel de líquido en ella no será el mismo que el que se aprecia en el tanque; sin embargo, la presión ejercida por el aire remanente en la manguera es linealmente proporcional al nivel, por lo que permite obtener una relación fácil de procesar de presión versus nivel. Para observar esta relación se efectuaron pruebas con sensores calibrados de presión, como el Simulador Multiparámetros Prosim4, que permitió corroborar la linealidad del sensor.

| Agua | Nivel | MPX2010 |
|------|-------|---------|
| L | cm | mV |
| 0 | 0 | 0 |
| 2 | 4.75 | 0.95 |
| 4 | 8.45 | 2 |
| 6 | 11.9 | 3.1 |
| 8 | 15.2 | 4.1 |
| 10 | 19.2 | 5.2 |
| 12 | 22.9 | 6.1 |
| 14 | 26.75 | 7.5 |
| 16 | 30.6 | 8.7 |
| 18 | 34 | 9.8 |
| 20 | 38.3 | 11 |



Cabe resaltar que los voltajes entregados por los dos sensores de presión se encuentra en el rango de los mV, por lo que para tener una lectura consistente para el conversor analógico digital del bloque de control, es necesaria una etapa de acondicionamiento de señal, que consistirá en una amplificación de estos valores a otros superiores que sí sean procesables por el microcontrolador.

Demostración de la Fórmula usada para el Cálculo de Solución ingresada al Tanque Pulmón

Datos:

Cloro HTH: concentración = 75%

1ppm = 1 mg/L

Proporción usada: 10 gramos de cloro HTH / litro

Procedimiento:

$$g \text{ Cl necesarios} = \frac{\text{concentración deseada} \left[\frac{\Delta mg \text{ Cl}}{L} \right] * \text{agua en el tanque [L]}}{\left[\frac{1000mg \text{ Cl}}{1.g \text{ Cl}} \right]} \dots (1)$$

$$\frac{1L}{10g \text{ HTH}} * \frac{1g \text{ HTH}}{0.75g \text{ Cl}} = \frac{1L}{7.5g \text{ Cl}} \dots (2): \text{Factor de conversión}$$

Para convertir los gramos de cloro necesarios a litros de solución necesarios, se multiplica (1) x (2):

$$\frac{\text{concentración deseada} \left[\frac{mg}{L} \right] * \text{agua en el tanque [L]}}{1000 \frac{mg \text{ Cl}}{g \text{ Cl}}} * \left[\frac{1L}{7.5g \text{ Cl}} \right] = \text{solución necesitada [L]}$$

$$\text{solución necesitada [L]} = \frac{\text{concentración deseada} * \text{volumen de agua en el tanque}}{7500}$$

l.q.q.d.

ARCL200 Manual

Announcements

1. When using, please comply with the instruction of the operation procedures and the announcements.
2. If discover the instrument work abnormally or damaged, please contact the dealer and do not repair by yourself.
3. In order to measure more accurately, the instrument must be often cooperated with electrode for calibration; if you have purchased electrode for nearly one year or the electrode has some quality problems, please pay attention to change.
4. Before calibrating, please preheat the instrument for 30 minutes.
5. If the products update, this manual will not give further note.

Product configuration

Please make sure the instrument, if the package is complete, if the package damage or have any shortage of accessories, please contact as soon as possible with the dealer, the configuration is as follows:

Standard configuration

One controller

One sensor with 3m cable

One flow cell

Two small tighten locks (holder)

One manual

One product certificate

Optional configuration

485 communication interface and 485 to 232 or 485 to USB connector

Main characteristics

1. Measurement principle: constant pressure
2. Large LCD screen
3. Several parameters display at the same time: Chlorine value, Temperature value, current and has range transfinite tip.
4. Has function of backing to factory setting.
5. Manual/automatic temperature compensation
6. Isolation 4-20mA output

Technical parameters

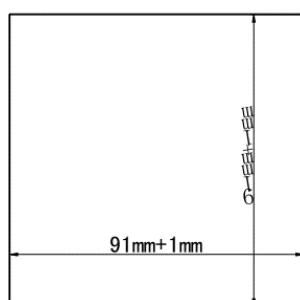
- 1.Measuring range: Residual chlorine:0-20ppm; Temp:0-60°C
- 2.Resolution:0.01mg/L,0.1°C
- 3.Precision:better than $\pm 1\%$ or $\pm 0.01\text{mg/L}$, $\pm 0.5^\circ\text{C}$
- 4.Manual/automatic temperature compensation (0-60°C)
- 5.The control interface: two groups of ON/OFF relay contact, divided into high and low alarm signal photoelectric isolation output. The third group relay: automatic cleaning control function analog output.
- 6.Signal isolation output: photoelectric coupler isolation protection 4 ~ 20mA signal output.
- 7.The electric apparatus: relay lag quantity any setting, relay load 3 A 220 vac/24 VDC.
- 8.Working conditions: environmental temperature is 0 ~60°C, relative humidity 90% or less
- 9.The output load: load $< 500 \Omega$ (0-10 ma), load $< 750 \Omega$ (4 -20ma)
- 10.Working voltage: 220 vac plus or minus 10%, 50/60 hz
- 11.Feet inches: 96 x 96 x 156 mm
- 12.Open hole size: 91 x 91 mm
- 13.Heavy volume: 0.9 Kg
- 14.The protection level: IP65

Instrument installation

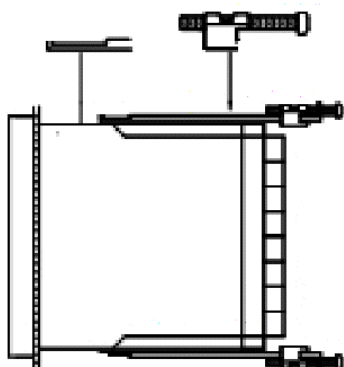
Controller installation

Instrument should be installed in clean, dry and ventilated good, no vibration position,surrounding should be no corrosive gas.

In the instrument ark or install panel open a rectangular incision.



Put instrument into instrument ark, and tighten the lock.



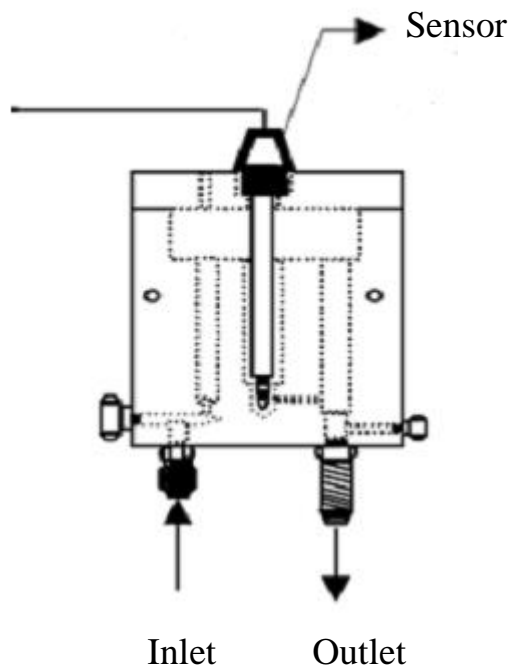
Sensor installation

When installing the sensor, please make sure the water pass the flow cell continuously and then insert the sensor into the hole, keep the sensor in the water. If there is no water in the flow cell for long time, please take out the sensor and put it in the original glue, make sure the glue have protection fluid. The detail is as below:

A. Take out the sensor, use your fingernails jog electrode rubber sleeve carefully (Attention: do not use hand to twist, in order to avoid damage the electrode), until the rubber pushed completely.

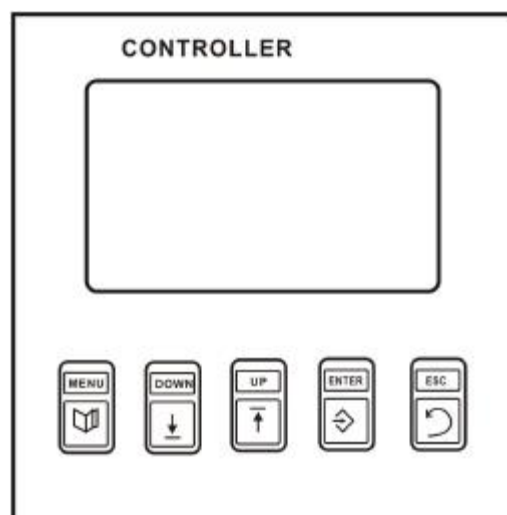
Attention: * If temporary test installation, please store the glue and protection fluid for using again after the measuring. * The protection fluid has a slight corrosion, please wash with clean water when touch.

B. Insert the sensor into the hole of flow cell (near the outlet hole). Please be careful not to damage the top of the glass head. Before installing, please do waterproof seal work with degreasing belt. Make sure the liquid keep a certain velocity and constant, the lowest flow is $15\text{cm}^3/\text{S}$.



Instrument panel and wiring instructions

Front panel button



1. MENU: MENU button or select key
2. DOWN: menu DOWN or numerical reduce key
3. UP: menu UP or numerical increase key
4. ENTER: confirm key
5. ESC: return or escape key (back to last menu)

Rear panel connection instructions

| | |
|--|--|
| 1.NO:H2 relay normally opened terminal | 11.EL:Counter potential electrode white line |
| 2.COM:H2 relay common terminal | 12.IN:Measuring sensor Black line |
| 3.NO:high relay normally opened terminal | 13.REF:Reference electrode Shielded wire |
| 4.COM:high relay common terminal | 14.T1:Temperature compensation |
| 5.NC:high relay normally closed terminal | 15.T2:Temperature compensation |
| 6.NO:low relay normally opened terminal | 16.GND:NC |
| 7.COM:low relay common terminal | 17.RS485A |
| 8.NC:low relay normally closed terminal | 18.RS485B |
| 9.L:220V power line | 19.4-20mA+ |
| 10.0V:Zero line | 20.4-20mA- |

Note:

- 1.Before switch on the power, make sure the connection is right, because wrong connection will make damage to the instrument.**
- 2.Separate the power line and signal line.**
- 3. Electrode sensor standard cable for 3 meters long, if need, the user can extend the cable, but not more than 15 meters, the extension cable need belt shielding line of silver plating three core low resistance cable. Extension cord should be used high insulation of the junction box connection.**

Instrument function setting

The main interface and the main menu

0.20 mg/L
25°C 4.12mA

Main
CL Cal
Meter Set

On the main menu, residual chlorine value is given priority to display and then temperature, current value.

Residual chlorine calibration

Due to the constant pressure method new residual chlorine electrode of zero potential and electrode slope are basically the same, the use of the process does not require calibration.

Along with the use process will gradually change, produce the aging phenomenon, which requires a certain period "calibration", to ensure the accuracy of measurement

The menu is as follows: in the main menu according to the key, choice residual chlorine calibration, press ENTER key into the residual chlorine calibration interface.

CL Cal
CL Zero Cal
CL Slope

Residual chlorine zero calibration

Before calibration gently blot the liquid of no chlorine (such as distilled water, pure water, etc.), press MENU option key, after popup cursor, press up and down key to change

Zero Cal
CL:0.00mg/L
VAL:0.000mg/L

Zero Cal
CL:0.00mg/L
VAL:0.000mg/L

Residual chlorine slope calibration

Calibration residual chlorine electrode of the slope. Enter the residual chlorine slope calibration menu.

Before calibration, the residual chlorine electrode in the known concentration of residual chlorine standard solution, operation instrument to press ENTER button, and then press MENU button key popup cursor, setting default value 0.20mg/L, press UP and DOWN key to change

the value into known density,such as 0.30mg/L,press ENTER key after stable,save data.

Residual chlorine value is stable(± 0.01 mg/L)refer to finishing calibration.

Press the ESC key to return to the last menu

Slope Cal
CL:0.18mg/L
VAL:0.20mg/L

Slope Cal
CL:0.18mg/L
VAL:0.30mg/L

Compensation setting

In the main menu press UP and DOWN key and choose parameter Settings,press ENTER key into the parameter Settings menu,as below,left for the first page, right for the second page.

Press UP and DOWN key to choose each Setting.

Compensate Set
Alarm Set
485 Comm
Current output

Backlight
Reset Factory

Press ENTER key into the compensation Settings menu. Press the MENU option key popup cursor, move the cursor, press UP and DOWN key to carry on the revision, the temperature can be divided into manual or automatic mode,if choose automatic and manual value is invalid, and the same.When equipped with NTC thermistor, automatic way of measurement is true value. If no NTC thermistor,then can choose manual input.

Temp Mode:Manual
Manu Temp:25°C

Press ENTER key and save data, press the ESC key to return to last menu.

Alarm Settings

In the parameter setting menu select alarm Settings, press ENTER key into the alarm set menu.

Press the MENU key, move the cursor, press UP and DOWN key to modify.

High:20.0
Lag H:0.5
Low:0.0

High:20.0
Lag H:0.5
Low:0.0

HIGH relay:in the actual measurement value higher than HIGH alarm setting HIGH value When action, the actual measured value to drop to below (high H value - lag H value) release.

LOW relay:in the actual measured value is lower than LOW alarm setting LOW value movement, the actual measured value to rise to higher than (LOW L value + lag L value)release. It's beneficial to extend the relay or ac contactor life. So the user must be set up according to the practical situation of high, low and hysteresis quantity.

485 communication

| |
|--------------------------------|
| <p>485 Comm Set ADD:01</p> |
|--------------------------------|

| |
|--------------------------------|
| <p>485 Comm Set ADD:01</p> |
|--------------------------------|

In the preferences menu option 485 communication, press ENTER key into 485 communication menu. According to the MENU table option key popup cursor, move the cursor, you can press UP and DOWN key to modify the key. Address (16 into system), and press the ENTER key stored data, press the ESC key to return to the menu at the next higher level.(note:specific agreement standard please consult the manufacturer or distributor)

Current output Settings

4 - 20 mA factory output corresponding residual chlorine, respectively 0 - 20 mg/L, but users can according to their own requirements, arbitrary set corresponding value to meet the needs of industrial control. According to the MENU MENU option key popup cursor, move the cursor,according to carry on the revision, the key to press ENTER key stored data, press the ESC key to return to the MENU at the next higher level.

Output current (mA): $I=16 \times (C-A)/(B-A)+4$

Note: I refers to current output

C for instrument current measuring residual chlorine value

A for setting of 4 ma corresponding number

B for setting 20ma corresponding numerical

| |
|---|
| <p>4-20mA Set 4 mA:0 20 mA:20</p> |
|---|

| |
|---|
| <p>4-20mA Set 4 mA:0 20 mA:20</p> |
|---|

Backlight time

In the parameters menu selection backlight time, press ENTER button to ENTER the Settings menu. According to the MENU table option key popup cursor, move the cursor, can press key modified. To press ENTER key stored data, press the ESC key to return to the menu at the next higher level. Backlight control, can let instrument more save electricity, protect the display screen and prolong its service life.

| |
|--------------------------------------|
| LIGHT SET Wait:02 MIN ALL ON:N |
|--------------------------------------|

| |
|--------------------------------------|
| LIGHT SET Wait:02 MIN ALL ON:N |
|--------------------------------------|

Recovery factory value

In the parameters menu selection recovery factory value, press ENTER key into the recovery factory value menu. According to the MENU MENU option key popup cursor, can press key modified. To press ENTER key stored data, press the ESC key to return to the menu at the next higher level.

| |
|-------------------------|
| Reset Factory NO |
|-------------------------|

| |
|------------------------------|
| Reset Factory YES YES |
|------------------------------|

Daily maintenance point:

Instrument is calibrated before delivery, the user can use it directly.

On-line monitoring measured medium should keep a certain velocity and constant, minimum flow is 15 cm³/ S.

General appearance of the failure rate is low.

Cotización N°: 20130228-051

Lima, 28 de febrero de 2013

Empresa : INVERSIONES CASSINELLI S.A.C.
 Atención : Julio Cassinelli
 Correo : cassinelli_lima@yahoo.com.mx
 Teléfono : (+51) 996 232 904
 Ref. Cliente : **Bombas dosificadoras ACQUATRON**



| Ítem | Descripción | Cant. | UM | Precio Neto Unit. | Precio Neto Total |
|------|---|-------|------|-------------------|-------------------|
| 01 | <p>Bomba dosificadora electromagnética de diafragma Marca: ACQUATRON Modelo: F1-MA 1.5/12 PP Fluido: Hipoclorito de sodio / Hipoclorito de calcio</p> <p>Características técnicas:</p> <ul style="list-style-type: none"> • Electromagnéticas a diafragma • De regulación manual mediante perilla del 0 al 100 % del caudal • Rango de caudal: 1.5 l/h • Rango de presión: 12 bar • Carcasa: PP (polipropileno) • Cabezal: PP (polipropileno) • Válvula de aspiración PP: bola boro silicato • Válvula de expulsión PP: bola boro silicato • O´rings: EPDM (caucho de etileno propileno dieno) • Diafragma: PTFE (teflón) • Incluye válvula manual de purga • Protección: IP65 (NEMA 4X) • Instalación en pared • Incluye tapa de protección de frente de la bomba ante posibles chorreaduras de producto • Dimensiones: 160mm x 153mm x 91mm • Peso: 2.2 kg • Tensión: 220 V +/- 10% • Amperaje: 1 • Frecuencia: monofásico 50/60 Hz • Incluye: <ul style="list-style-type: none"> ○ 2 m de manguera de aspiración de PVCC ○ 2 m de manguera de expulsión de PE ○ 2 m de manguera de purga de PVCC ○ 1 válvula de pie con filtro ○ 1 válvula de inyección ○ 1 manual de instalación y mantenimiento ○ 02 tornillos y bulones para anclaje | 1 | Uni. | 225.00 | 225.00 |

Cotización N°: 20130228-051

| TOTAL: | Moneda | Precio Neto Total |
|--------|--------|-------------------|
| | USD | 225.00 |

CONDICIONES COMERCIALES:

***Precio total NO incluye IGV**

| | | |
|----------------------|---|--|
| Moneda | : | Dólares Americanos |
| Forma de pago | : | Al contado |
| Plazo de entrega | : | Inmediato en stock, salvo previa venta |
| Validez de la oferta | : | 30 días |
| Garantía | : | 1 año, por defectos de fabricación. Queda excluida toda garantía, la misma que de ser el caso se perderá, si los equipos han sido expuestos o sometidos a: |

1. Mantenimiento, reparación, instalación, manipulación, embalaje, transporte, almacenamiento, operación o uso diferente para el que fue cotizado, o que no esté en conformidad con las instrucciones dadas en los manuales de instalación, operación y mantenimiento de los equipos.
2. Alteración, modificación o reparación por alguien distinto a aquellos específicamente autorizados por BDEC S.A.C.
3. Accidente, contaminación, daño por materiales extraños, daño, abuso, descuido o negligencia.
4. Desgaste normal de piezas ocasionadas por las operaciones.

Para los productos que BDEC S.A.C. distribuye y/o comercializa, se trasladará al comprador la garantía que otorga cada fabricante. Queda claramente establecido que BDEC S.A.C. no otorga garantías directamente por lo que no se otorga más garantía que la que el fabricante ofrece y se traslada al operador.

Agradeciendo por anticipado su atención y esperando en poder servirles quedamos de usted.

Atte.,
André Sheldon A.
Ejecutivo de cuentas

ANEXO 8_Código completo del Arduino

```

#include <TimerOne.h>
#include <EEPROM.h>
#include <math.h>

int ini_process=1, estado=LOW; //EL PROCESO INICIALMENTE SE ACTIVA, PARA SENSAR AL INICIO DE TODO
float ppm=0.00;
int error_1=0;
int sin_cloro=0;
int v=0;
int puerto;
int bandera=0;
double distancia, distance; //DECLARACION DE VARIABLES
int tiempo;
double aux,volumen;
float delta_ppm;
double c=0.00;
long kpa1, kpa;

/* se quiere tener como preferencia 2.3 ppm con margenes max:2.5 y min:2.1 ; en ese rango no se activa nada

float td=0, tdos; /* tiempo de dosificacion

float pp=0;
int primera=0;

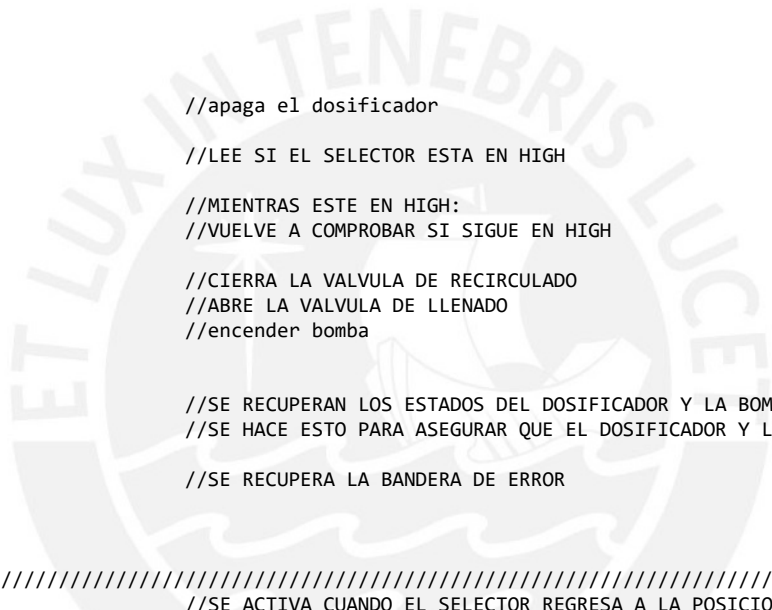
//////////////////////////////////////
//CONFIGURACION DE GPIO, ADCs, E INTERRUPCIONES

void setup()
{
  pinMode(29,OUTPUT); //led proceso general
  pinMode(25,OUTPUT); //led sin cloro
  pinMode(27,OUTPUT); //led proceso clorinacion
  pinMode(28, OUTPUT); //dosificador
  pinMode(22,OUTPUT); //electrovalvula recirc
  pinMode(24,OUTPUT); //electrovalvula llenado
  pinMode(26,OUTPUT); //bomba
  pinMode(A0, INPUT); //sensor de cloro
  pinMode(A1, INPUT); //sensor de presion 50kpa
  pinMode(A2,INPUT); //seNsor de 10kpa

  pinMode(2,INPUT); // selector en high
  pinMode(3,INPUT); // selector en low
  pinMode(19, INPUT); //pulsador borrador_error_1

  attachInterrupt(1,ISR_llenado,RISING); // ACTIVA LA INTERRUPCION DE LLENADO, EL SELECTOR
  attachInterrupt(0,ISR_ciclonormal,FALLING); // REGRESA EL SISTEMA AL FUNCIONAMIENTO NORMAL AL VOLVER A GIRAR EL SELECTOR

```



```
attachInterrupt(4,ISR_borrar_eeeprom,RISING);
}

/////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//SE ACTIVA CUANDO EL SELECTOR ES COLOCADO EN POSICION LLENADO
void ISR_llenado()
{
  int x;
  int y;
  int z;

  digitalWrite(28,LOW); //apaga el dosificador

  x=digitalRead(2); //LEE SI EL SELECTOR ESTA EN HIGH
  while(x==1)
  {
    //MIENTRAS ESTE EN HIGH:
    x=digitalRead(2); //VUELVE A COMPROBAR SI SIGUE EN HIGH

    digitalWrite(22,LOW); //CIERRA LA VALVULA DE RECIRCULADO
    digitalWrite(24,HIGH); //ABRE LA VALVULA DE LLENADO
    digitalWrite(26,HIGH); //encender bomba
  }

  y= EEPROM.read(1); //SE RECUPERAN LOS ESTADOS DEL DOSIFICADOR Y LA BOMBA DE LA EEPROM
  digitalWrite(26,y); //SE HACE ESTO PARA ASEGURAR QUE EL DOSIFICADOR Y LA BOMBA SIGAN EN SU ESTADO ANTERIOR
  z=EEPROM.read(2);
  digitalWrite(28,z);
  error_1=EEPROM.read(0); //SE RECUPERA LA BANDERA DE ERROR

}

/////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//SE ACTIVA CUANDO EL SELECTOR REGRESA A LA POSICION INCIAL
void ISR_ciclonormal()
{
  //YA LEYO QUE EL SELECTOR ESTA EN LOW

  int y; //OBTIENE EL ESTADO ANTERIOR DEL DOSIFICADOR
  y=digitalRead(2); //CIERRA VALVULA DE LLENADO
  digitalWrite(24,LOW); //CIERRA VALVULA DE LLENADO
  digitalWrite(22,HIGH); //ABRE LA VALVULA DE RECIRCULADO
  digitalWrite(26,EEPROM.read(1)); //LEE EL ESTADO ANTERIOR DE LA BOMBA Y LO COLOCA DE NUEVO
  error_1=EEPROM.read(0); //LEE EL ESTADO DE ERROR 1

}

/////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//BORRA EL BIT 0 DE LA EEPROM (ERROR 1)
```

ANEXO 8_Código completo del Arduino

```

void ISR_borrar_eeprom()
{
  EEPROM.write(0,0);
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//interrupcion que hace parpadear el led de encendido.
void ISR_led_parpadeo()
{
  digitalWrite(29,estado);
  estado=!estado;
  delay(1000); //PARPADEO DE 1 SEGUNDO
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//SUBROUTINA QUE CONTROLA EL RECIRCULADO ENCENDIENDO LA BOMBA
//tiempo en minutos
int recirculado(int tiempo)
{
  digitalWrite(28,LOW); //ASEGURA EL APAGADO DEL DOSIFICADOR
  EEPROM.write(2,LOW); //GUARDA EN EEPROM
  digitalWrite(26,HIGH); //ENCIENDE BOMBA
  EEPROM.write(1,HIGH); //GUARDA EN EEPROM
  delay(tiempo*60000); //tiempo que esta encendido la bomba de recirculacion en minutos
  digitalWrite(26,LOW); //se apaga la bomba de recirculacion
  EEPROM.write(1,LOW); //GUARDA EN EEPROM
  error_1=EEPROM.read(0);
  return 0;
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//LEE LA PRESION EN LA MANGUERA, PRODUCIDA POR EL NIVEL DE AGUA
void leer_nivel_agua ()
{
  kpa1=analogRead(A1); //OBTIENE UN NUMERO EN EL ADC, DE 0 A 1023
  kpa1=double(kpa1);
  distancia=double((0.00285380117*kpa1)-0.4394385); //CONVIERTE LOS BITS A ALTURA, TOMANDO EN CUENTA QUE EL ADC_
  //TIENE 10 BITS (1023 EQUIVALE A 5 VOLTIOS EN LA ENTRADA),_
  //Y 5 VOLTIOS SIGNIFICAN 2.47 METROS
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//CALCULO DEL VOLUMEN DE AGUA SEGUN LA ALTURA

```

ANEXO 8_Código completo del Arduino

```

double MyVolumen(double dist)
{
  /*    V=Area x L
  Area=(R^2/2)x[angle_rad - seno(angle_rad)], donde angle_rad <-- angle_sexagesimal
  angle_sexa=2xArcCos(angle), donde angle= d/R <--- d =dist_ultrason-R          */

  double dist1;
  double L=4.68,R2,expo2;          /*variables*/
  double angle,angle_sexa,angle_rad,area,vol,a;  /*variables results parciales*/
  float expo,R=1.246;             /*R y expo se usaran en "pow" que admite float*/
  R2=(double)R;                   /*R2 es para calculos en double DE R, OPERADOR CAST
  dist1=2*R2-dist;                //agregado por el sensor de presion
  angle=(dist1-R2)/R2;
  a=Myacos(angle);
  angle_sexa=2*Myacos(angle);
  angle_rad=angle_sexa*3.1416/180.0;
  expo=pow(R,2);                  /*salida de pow es float*/
  expo2=(double)expo;            /*expo2 es para calculos en double*/
  area=((expo2)/2.00)*(angle_rad-sin(angle_rad));

  vol = area*L*1000;              /* vol (m3)x1000 = vol(Litros) */
  return vol;
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
double Myacos(double x)          //SUBROUTINA PARA OPERADOR ARC COS
{
  double ret, val;
  val = 180.00 /3.1416;
  ret = acos(x) * val;
  return ret;
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//de la grafica, la relacion entre el voltaje entre el INA y la altura es 7.3313

void analizar_nivel_cloro()
{
  long kpa1, kpa;
  double altura_cloro;
  kpa1=analogRead(A2);           //PROCESA EL DATO COMO VOLTAJE Y LO CONVIERTE A BITS
  altura_cloro= kpa1*(5/1023)*(7.3313); //CONVIERTE LOS BITS A ALTURA EN EL TANQUE DE SOLUCION
  if (altura_cloro<12.5)         //EQUIVALENTE A 6.13 LITROS EN EL TANQUE DE SOLUCION
  {
    sin_cloro=1;
  }
}

```

ANEXO 8_Código completo del Arduino

```
    }
    else
    {
        sin_cloro=0;
    }
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//ENCIENDE EL DOSIFICADOR POR "tiemps" SEGUNDOS
int cloro_on(float tiemps)
{
    digitalWrite(28,HIGH);           //se enciende el motor para dosificar
    digitalWrite(26,HIGH);         //ENCIENDE BOMBA PARA RECIRCULAR
    EEPROM.write(2,HIGH);
    EEPROM.write(1,HIGH);
    delay(tiemps*1000/10);         //tiempo que esta encendido el dosificador
    digitalWrite(28,LOW);          //se apaga el motor de dosificacion
    digitalWrite(26,LOW);          //APAGA BOMBA
    EEPROM.write(1,LOW);
    EEPROM.write(2,LOW);
    return 0;
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//CALCULO DEL TIEMPO DE DOSIFICACION SEGUN VOLUMEN DE AGUA Y_
//DIFERENCIA (DELTA) DE PPM
float calc_t_dos(double dist)
{
    distance=dist;
    volumen= MyVolumen(distance);
    delta_ppm= 2.3 - ppm;          //cuanto menos de ppm hay en el tanque
    volumen=(float)volumen;
    tdos=volumen*delta_ppm/18.75;  //FACTOR DE CONVERSION OBTENIDO DE LA CONCENTRACION DE LA SOLUCION (10G / L)_
    return tdos;                  //Y EL FLUJO DEL DOSIFICADOR (150 mL/S)
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////
//CONVERSION DE LA LECTURA OBTENIDA DEL SENSOR DE CLORO
void leer_ppm()
{
    float pp, p;
    float x;
    digitalWrite(26,HIGH);        //ENCIENDE BOMBA
    EEPROM.write(1,HIGH);
    delay(8000);
    p=analogRead(A0);             //LO LEE COMO VOLTAJES DE 1 A 5V
}
```

```

digitalWrite(26,LOW);
EEPROM.write(1,LOW);
pp=0.0197*p+0.3424;
x=0.3134*pp-1.2613;
ppm=x;
}

////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////////

void loop()
{
digitalWrite(26,LOW); //APAGA BOMBA
EEPROM.write(1,LOW); //GUARDA EL APAGADO DE BOMBA EN EEPROM
digitalWrite(24,LOW); //CIERRA VALVULA LLENADO
digitalWrite(22,HIGH); //ABRE VALVULA RECIRCULADO
loopproceso:

    if(ini_process == 1)
    {
        digitalWrite(26,HIGH); //ENCIENDE LA BOMBA PARA INICIAR LA RECOLECCION DE DATOS
        EEPROM.write(1,HIGH); //GUARDA ESE ESTADO EN LA EEPROM
        digitalWrite(29, HIGH); //ENCIENDE LED DE PROCESO GENERAL
        Timer1.stop();
        Timer1.detachInterrupt(); //APAGA LA INTERRUPCION DEL TIMER

medirppm:
        digitalWrite(22,HIGH); //electrovalvula encendida
        delay(5*1000); //estabilizar flujo constante
        leer_ppm();

error1activado:
        error_1=EEPROM.read(0);
        if(error_1>2) //SI EL SISTEMA FALLO 3 VECES EN NORMALIZAR LA CONCENTRACION DE CLORO
        {
            Timer1.stop();
            Timer1.detachInterrupt();
            Timer1.initialize(500000);
            Timer1.attachInterrupt(ISR_led_parpadeo); //PARPADEO DE LUZ VERDE

error1loop:
            //BUCLE DE ERROR
            error_1=EEPROM.read(0);
            if(error_1==0)
            {
                goto loopproceso;
            }
        }
    }
else

```


ANEXO 8_Código completo del Arduino

```

    {
    if(sin_cloro==1)
    {
analizar_nivel_cloro1:
        analizar_nivel_cloro();
        if(sin_cloro==0)
        {
            digitalWrite(25,LOW);
            Timer1.stop();
            Timer1.detachInterrupt();
            digitalWrite(29,HIGH);
            EEPROM.write(0,0);
            goto medirppm;
        }
        else
        {
            goto analizar_nivel_cloro1;
        }
    }
    else
    {
        goto error1loop;
    }
}
else
{
    if(ppm>2.43)
    {
        recirculado(20);
        error_1++;
        EEPROM.write(0,error_1);
        goto medirppm;
    }
    else
    {
        if(ppm<2.17)
        {
            analizar_nivel_cloro();

            if(sin_cloro==1)

```

//ESTE ES EL CASO DE ERROR POR FALTA DE SOLUCION

//CONSTANTEMENTE EVALUA EL NIVEL DE SOLUCION
//SI ES QUE YA SE HA LLENADO EL TANQUE DE SOLUCION...

//error1<-0

//POR ENCIMA DEL LIMITE SUPERIOR: RECIRCULA PARA DISMINUIR LA CONCENTRACION DE CLORO

//20 MINUTOS DE RECIRCULACION PARA INTENTAR BAJAR LA CONCENTRACION DE CLORO

//POR DEBAJO DEL LIMITE INFERIOR: DOSIFICA PARA AUMENTAR CONCENTRACION DE CLORO

//PRIMERO ANALIZA SI QUEDA SOLUCION EN EL TANQUE DE 20 LITROS

ANEXO 8_Código completo del Arduino

```

{
  digitalWrite(25,HIGH);
  error_1=3;
  EEPROM.write(0,error_1);
  goto error1activado;
}
else
{
  digitalWrite(27,HIGH);
  leer_nivel_agua();
  if (kpa1>168) //CALCULA LA ALTURA DEL AGUA EN EL TANQUE PULMON
  { //LIMITE INFERIOR, 30 CENTIMETROS DE AGUA EN EL TANQUE COMO MINIMO
    distancia=double(distancia);
  }
  else
  {
    goto apagadoledcloro;
  }

  td=calc_t_dos(distancia); // calculo del tiempo de dosificacion
  cloro_on(td); // Dosificar por td segundos
  recirculado (5); // recircular 5 minutos

apagadoledcloro:

  digitalWrite(27,LOW); //apagar led clorinacion
  error_1=EEPROM.read(0);
  error_1++;
  EEPROM.write(0,error_1) ;
  goto medirppm;
}
}

else
{
  error_1=0; //LA CONCENTRACION ESTA EN EL RANGO DESEADO
  EEPROM.write(0,error_1); //SE REINICIA EL ERROR1
  ini_process=0;

casifinal:

  ini_process=0; //LA BANDERA DE PROCESO SE COLOCA EN LOW
  digitalWrite(29,HIGH);

```

ANEXO 8_Código completo del Arduino

```
digitalWrite(26,LOW);
EEPROM.write(1,LOW);
Timer1.stop();
Timer1.detachInterrupt();
    }
}
}
else
{
    delay(150);
    c++;
    if(c==800.00*60.00*1.00)
    {
        ini_proceso=1;
        c=0.00;
    }
    goto loopproceso;
}
}
```

//150 mS
//150 mS * 800 * 60 = 7200000 mS = 7200 S = 2 HORAS
//BANDERA DE PROCESO, EL BUCLE SE QUEDA CONTANDO HASTA QUE PASAN 2 HORAS

Application Note AN-3003

Applications of Random Phase Crossing Triac Drivers

Construction

The MOC30XX family of random phase (non-zero crossing) triac drivers consist of an aluminum gallium arsenide infrared LED, optically coupled to a silicon detector chip. These two chips are assembled in a 6 pin DIP package, providing 7.5KV_{AC(PEAK)} of insulation between the LED and the output detector. These output detector chips are designed to drive triacs controlling loads on 115 and 220V AC power lines. The detector chip is a complex device which functions in the same manner as a small triac, generating the signals necessary to drive the gate of a larger triac such as Fairchild's FKPF12N80. The MOC30XX triacs are capable of controlling larger power triacs with a minimum number of additional components.

Table 1 lists the members of the MOC30XX random phase triac driver family. The family is divided by blocking voltage, V_{DM}, and input LED trigger sensitivity, I_{FT}. MOC3010/1/2 are rated at 250V, the MOC3020/1/2/3 are 400VAC, and the MOC3051/2 have a V_{DM} of 600V.

Basic Electrical Description

The AlGaAs LED has a nominal 1.3 V forward drop at 10 mA and a reverse breakdown voltage greater than 3 V. The maximum current to be passed through the LED is 60 mA.

The detector has a minimum blocking voltage of 250 Vdc in either direction in the off state. In the on state, the detector will pass 100 mA in either direction with less than 3 V drop

across the device. Once triggered into the on (conducting) state, the detector will remain there, even if no current flows through the LED, until the terminal current drops below the holding current (typically 100 μA) at which time the detector reverts to the off (non-conducting) state. The detector may be triggered into the on state by exceeding the forward blocking voltage, by voltage ramps across the detector at rates exceeding the static dv/dt rating, or by photons from the LED. The LED is guaranteed by the specifications to trigger the detector into the on state when the current passing through the LED is equal to, or greater than the I_{FT(max)} specification. For example the MOC3011M requires at least 10mA of LED current to guarantee turn-on. A similar device, the MOC3012M, has exactly the same characteristics except it requires only 5 mA to trigger.

Since these devices look essentially like a small optically triggered triac, we have chosen to represent it as shown in Figure 1.

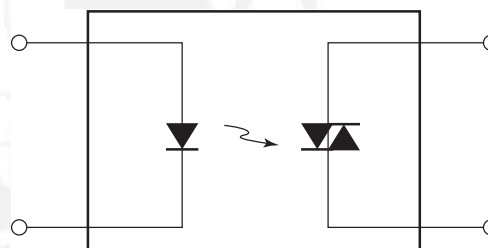


Figure 1. Schematic Representation of an Optically Coupled Random Phase Triac Driver

| | Random Phase Triac Optocouplers | | | | | | |
|------------------------|---------------------------------|--------------------------|-------------------------|-------------------------|---------------------|---------------------------|---------------------------|
| | Part Number | I _{FT} (ma) max | V _{TM} (V) max | V _{DM} (V) min | I _H (μA) | I _{DRM} (nA) max | V _{ISO} AC[PEAK] |
| <p>*Do not connect</p> | MOC3010M | 15 | 3 | 250 | 100 | 100 | 7.5kV |
| | MOC3011M | 10 | 3 | 250 | 100 | 100 | 7.5kV |
| | MOC3012M | 5 | 3 | 250 | 100 | 100 | 7.5kV |
| | MOC3020M | 30 | 3 | 400 | 100 | 100 | 7.5kV |
| | MOC3021M | 15 | 3 | 400 | 100 | 100 | 7.5kV |
| | MOC3022M | 10 | 3 | 400 | 100 | 100 | 7.5kV |
| | MOC3023M | 5 | 3 | 400 | 100 | 100 | 7.5kV |
| | MOC3051M | 15 | 2.5 | 600 | 280 | 100 | 7.5kV |
| | MOC3052M | 10 | 2.5 | 600 | 280 | 100 | 7.5kV |

Table 1.

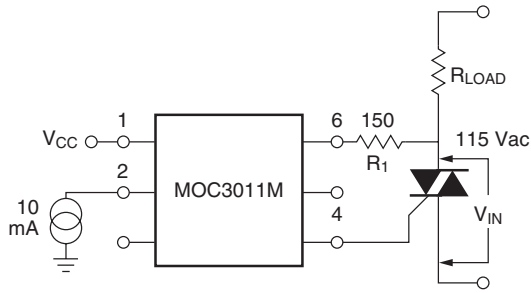
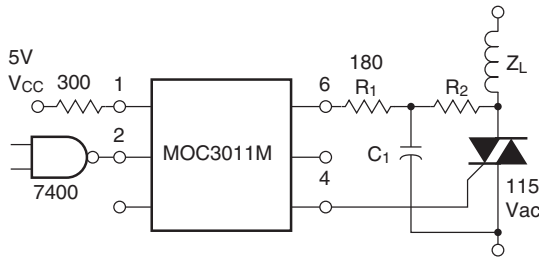


Figure 2. Simple Triac Gating Circuit



NOTE: Circuit supplies 25mA drive to gate of triac at $V_{in} = 25V$ and $T_A < 70^\circ C$

| TRIAC | | |
|----------|-------|-----|
| I_{GT} | R_2 | C |
| 15 mA | 2400 | 0.1 |
| 30 mA | 1200 | 0.2 |
| 50 mA | 800 | 0.3 |

Figure 3. Logic to Inductive Load Interface

Using the MOC3011M as a Triac Driver

Triac Driving Requirements

Figure 2 shows a simple triac driving circuit using the MOC3011M. The maximum surge current rating of the MOC3011M sets the minimum value of R_1 through the equation:

$$R_1 (\text{min}) = V_{in(pk)} / 1.2A$$

If we are operating on the 115 Vac nominal line voltage, $V_{in(pk)} = 180 V$, then

$$R_1 (\text{min}) = V_{in(pk)} / 1.2A = 150 \text{ ohms.}$$

In practice, this would be a 150 or 180 ohm resistor. If the triac has $I_{GT} = 100 \text{ mA}$ and $V_{GT} = 2 V$, then the voltage V_{in} necessary to trigger the triac will be given by,

$$V_{inT} = R_1 \cdot I_{GT} + V_{GT} + V_{TM} = 20 V.$$

Resistive Loads

When driving resistive loads, the circuit of Figure 2 may be used. Incandescent lamps and resistive heating elements are the two main classes of resistive loads for which 115 Vac is utilized. The main restriction is that the triac must be properly chosen to sustain the proper inrush loads. Incandescent lamps can sometimes draw a peak current known as “flash-over” which can be extremely high, and the triac should be protected by a fuse or rated high enough to sustain this current.

Line Transients-Static dv/dt

Occasionally transient voltage disturbances on the ac line will exceed the static dv/dt rating of the MOC3011M. In this case, it is possible the MOC3011M and the associated triac will be triggered on. This is usually not a problem, except in unusually noisy environments, because the MOC3011M and its triac will commute off at the next zero crossing of the line voltage, and most loads are not noticeably affected by an occasional single half-cycle of applied power. See Figure 4 for typical dv/dt versus temperature curves.

Inductive Loads-Commutating dv/dt

Inductive loads (motors, solenoids, magnets, etc.) present a problem both for triacs and for the MOC3011M because the voltage and current are not in phase with each other. Since the triac turns off at zero current, it may be trying to turn off when the applied current is zero but the applied voltage is high. This appears to the triac like a sudden rise in applied voltage, which turns on the triac if the rate of rise exceeds the commutating dv/dt of the triac or the static dv/dt of the MOC3011M.

Snubber Networks

The solution to this problem is provided by the use of “snubber” networks to reduce the rate of voltage rise seen by the device. In some cases, this may require two snubbers-one for the triac and one for the MOC3011M. The triac snubber is dependent upon the triac and load used and will not be discussed here. In many applications the snubber used for the MOC3011M will also adequately protect the triac.

In order to design a snubber properly, one should really know the power factor of the reactive load, which is defined as the cosine of the phase shift caused by the load. Unfortunately, this is not always known, and this makes snubbing network design somewhat empirical. However, a method of designing a snubber network may be defined, based upon a typical power factor. This can be used as a “first cut” and later modified based upon experiment.

Assuming an inductive load with a power factor of $PF = 0.1$ is to be driven. The triac might be trying to turn off when the applied voltage is given by

$$V_{to} = V_{pk} \sin \theta = V_{pk} = 180 V$$

First, one must choose R_1 (Figure 3) to limit the peak capacitor discharge current through the MOC3011M. This resistor is given by

$$R_1 = V_{pk}/I_{max} = 180/1.2 \text{ A} = 150\Omega$$

A standard value, 180 ohm resistor can be used in practice for R_1 .

It is necessary to set the time constant for $\tau = R_2C$. Assuming that the triac turns off very quickly, we have a peak rate of rise at the MOC3011M given by

$$dv/dt = V_{to}/\tau = V_{to}/R_2C$$

Setting this equal to the worst case dv/dt (static) for the MOC3011M which we can obtain from Figure 4 and solving for R_2C :

$$dv/dt(T_j = 70^\circ\text{C}) = 0.8 \text{ V}/\mu\text{s} = 8 \times 10^5 \text{ V/s}$$

$$R_2C = V_{to}/(dv/dt) = 180/(8 \times 10^5) = 225 \times 10^{-6}$$

The largest value of R_2 available is found, taking into consideration the triac gate requirements. Using Fairchild's power triac, FKPF12N80, $I_{GT} = 30 \text{ mA}$. If the triac is to be triggered when $V_{in} \leq 40\text{V}$:

$$(R_1 + R_2) = V_{in}/I_{GT} = 40/0.030 \approx 1.33 \text{ k}$$

If we let $R_2 = 1200 \Omega$ and $C = 0.1 \mu\text{F}$, the snubbing requirements are met. Triacs having less sensitive gates will require that R_2 be lower and C be correspondingly higher as shown in Figure 3.

Input Circuitry

Resistor Input

When the input conditions are well controlled, as for example when driving the MOC3011M from a logic gate, only a single resistor is necessary to interface the gate to the input LED of the MOC3011M. The resistor should be chosen to set the current into the LED to be a minimum of 10 mA but no more than 50 mA. 15 mA is a suitable value, which allows for considerable degradation of the LED over time, and assures a long operating life for the coupler. Currents higher than 15 mA do not improve performance and may hasten the aging process inherent in LED's. Assuming the forward drop to be 1.5 V at 15 mA allows a simple formula to calculate the input resistor.

$$R_1 = (V_{CC} - 1.5)/0.015$$

Examples of resistive input circuits are seen in Figures 1 and 5.

Increasing Input Sensitivity

In some cases, the logic gate may not be able to source or sink 15 mA directly. CMOS, for example, is specified to have only 0.5 mA output, which must then be increased to drive the MOC3011M. There are numerous ways to increase this current to a level compatible with the MOC3011M input requirements; an efficient way is to use the Fairchild TinyLogic™, NC7SZ04 shown in Figure 5.

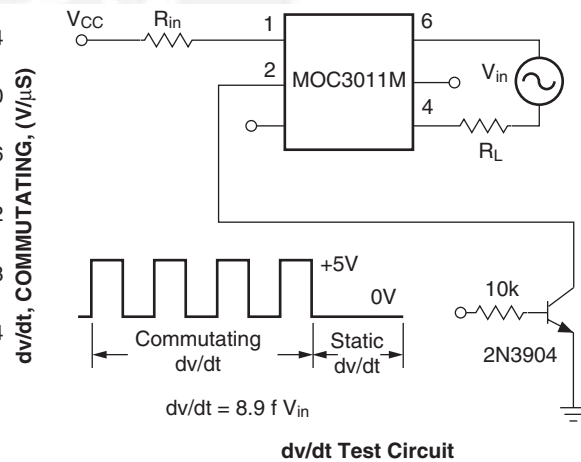
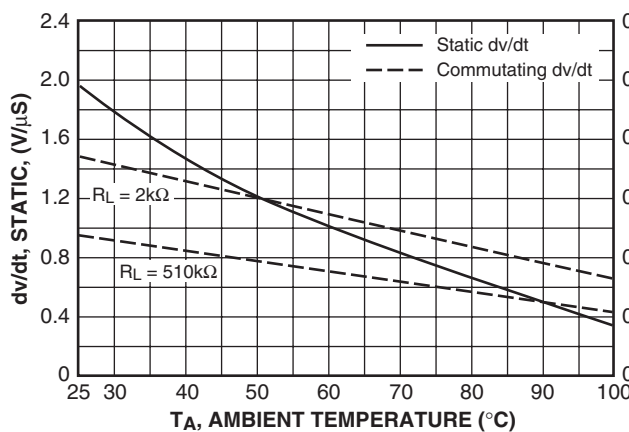


Figure 4. dv/dt versus Temperature

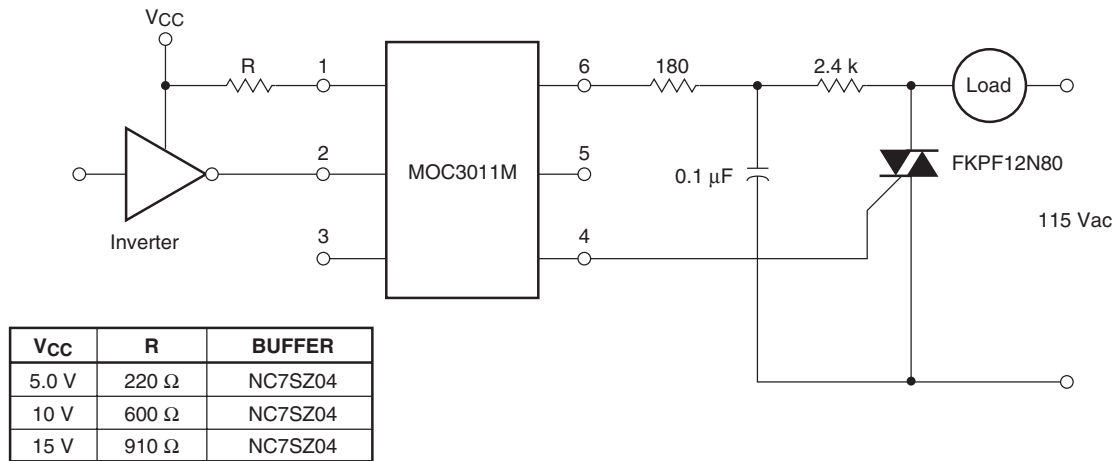


Figure 5. MOS to AC Load Interface

Input Protection Circuits

In some applications, such as solid state relays, in which the input voltage varies widely the designer may want to limit the current applied to the LED of the MOC3011M. The circuit shown in Figure 6 allows a non-critical range of input voltages to properly drive the MOC3011M and at the same time protects the input LED from inadvertent application of reverse polarity.

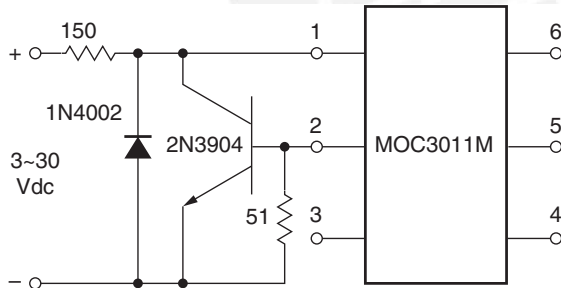


Figure 6. MOC3011M Input Protection Circuit

LED Lifetime

All light emitting diodes slowly decrease in brightness during their useful life, an effect accelerated by high temperature and high LED currents. To allow a safety margin and ensure long service life, the MOC3011M is actually tested to trigger at a value lower than the specified 10 mA input

threshold current. The designer can therefore design the input circuitry to supply 10 mA to the LED and still be sure of satisfactory operation over a long operating lifetime. On the other hand, care should be taken to ensure that the maximum LED input current (50 mA) is not exceeded or the lifetime of the MOC3011M may be shortened.

Applications Examples

Using the MOC3011M on 240 Vac Lines

The rated voltage of a MOC3011M is not sufficiently high for it to be used directly on 240 Vac line; however, the designer may attach two of them in series. When used this way, two resistors are required to equalize the voltage dropped across them as shown in Figure 7.

Remote Control of ac Voltage

Local building codes frequently require all 115 Vac light switch wiring to be enclosed in conduit. By using a MOC3011M, a triac, and a low voltage source, it is possible to control a large lighting load from a long distance through low voltage signal wiring which is completely isolated from the ac line. Such wiring usually is not required to be put in conduit, so the cost savings in installing a lighting system in commercial or residential buildings can be considerable. An example is shown in Figure 8. Naturally, the load could also be a motor, fan, pool pump, etc.

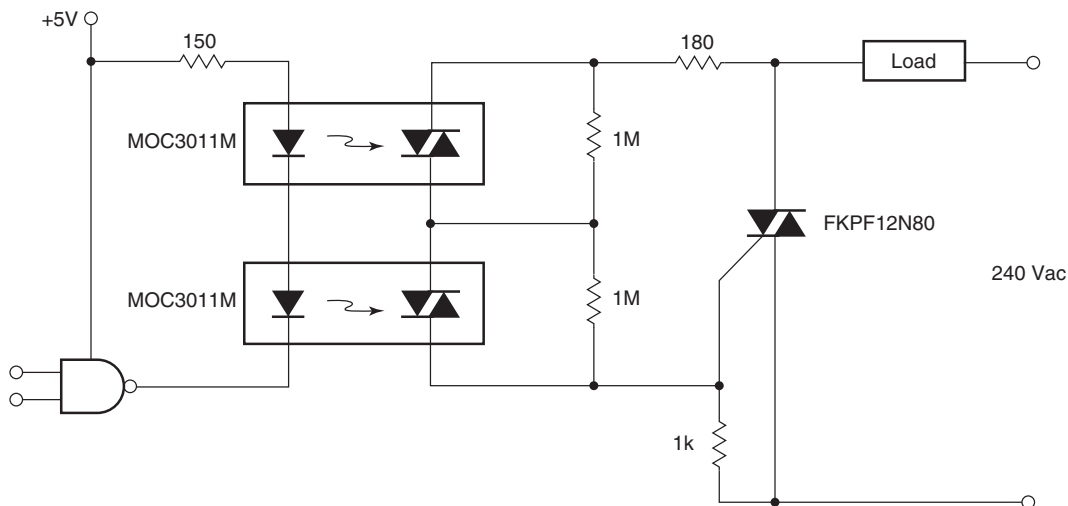


Figure 7. 2 MOC3011M Triac Drivers in Series to Drive 240 V Triac

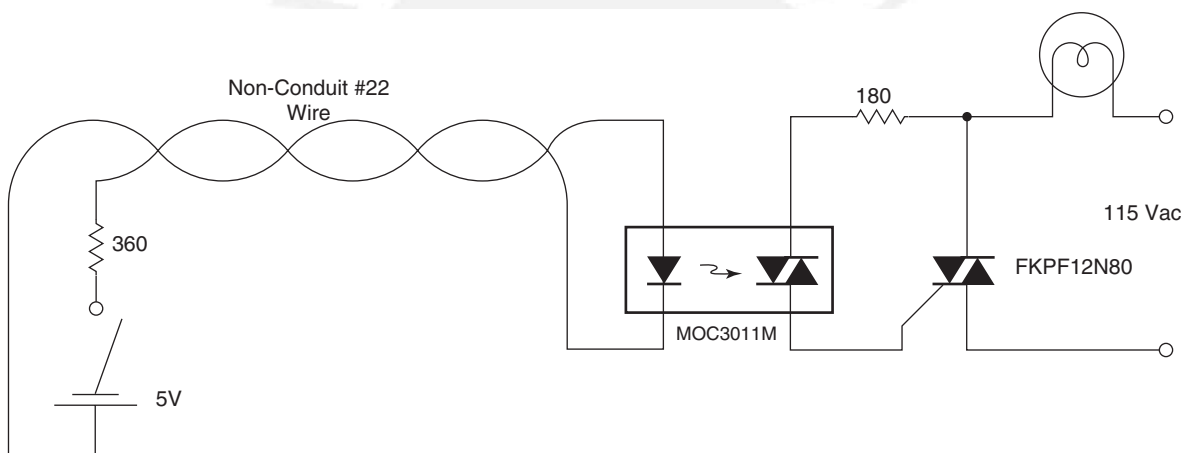


Figure 8. Remote Control of AC Loads through Low Voltage Non-Conduit Cable

Solid State Relay

Figure 9 shows a complete general purpose, solid state relay snubbed for inductive loads with input protection. When the designer has more control of the input and output conditions, he can eliminate those components which are needed for his particular application to make the circuit more cost effective.

Interfacing Microprocessors to 115 Vac Peripherals

The output of a typical microcomputer input-output (I/O) port is a TTL-compatible terminal capable of driving one or two TTL loads. This is not quite enough to drive the MOC3011M, nor can it be connected directly to an SCR or

triac, because computer common is not normally referenced to one side of the ac supply. The Fairchild TinyLogic™ NC7SZ04 UHS inverter can provide the LED current drive required by the MOC3011M family. If the second input of a 2 input gate is tied to a simple timing circuit, it will also provide energization of the triac only at the zero crossing of the ac line voltage as shown in Figure 10. This technique extends the life of incandescent lamps and reduces EMI generated by load switching. Of course, zero crossing can be generated within the micro-computer itself, but this requires considerable software overhead and usually just as much hardware to generate the zero-crossing timing signals.

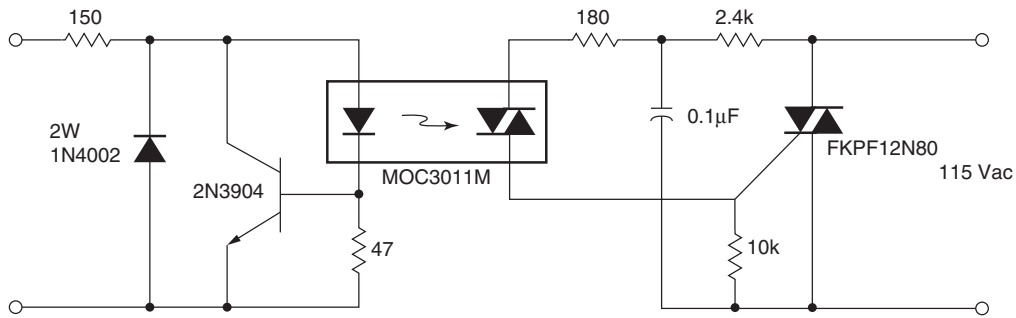


Figure 9. Solid-State Relay

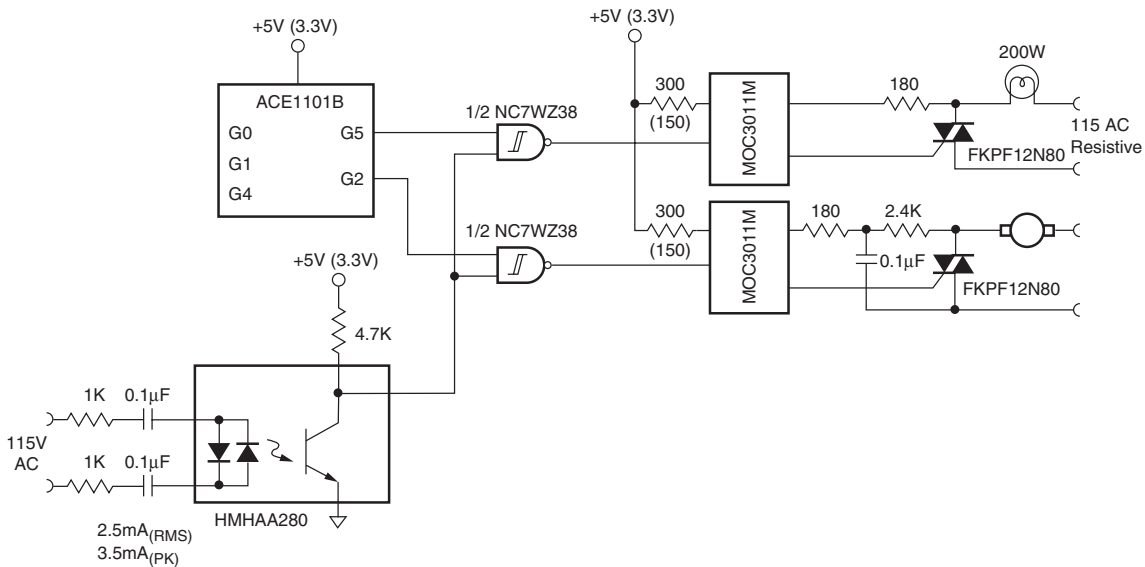


Figure 10. Interfacing an Arithmetic Controller Engine to 115 Vac Loads

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