普通高等教育"十二五"规划教材

电厂化学专业英语

李宇春　张瑛洁　张　芳　赵晓丹　编

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内 容 提 要

本书为普通高等教育“十二五”规划教材。

全书共 7 章，详细介绍了电厂化学相关的系统、原理、监督和处理技术，主要内容包括补给水处理、凝结水精处理、腐蚀与防护、水化学控制工况、蒸汽化学控制工况、水汽监测及化学仪表控制等。

本书可作为普通高等教育能源与动力工程、材料科学与工程、应用化学、化学工程与工艺及相关专业本科生和研究生的教材，也可供从事火电厂、核电厂化学环境及相关工作的技术人员参考。

图书在版编目（CIP）数据

电厂化学专业英语 / 李宇春等编. —北京：中国电力出版社，2011.10

普通高等教育“十二五”规划教材

ISBN 978-7-5123-2190-8

Ⅰ. ①电… Ⅱ. ①李… Ⅲ. ①电厂化学－英语－高等学校－教材 Ⅳ. ①H31

中国版本图书馆 CIP 数据核字（2011）第 203881 号

中国电力出版社出版、发行

（北京市东城区北京站西街 19 号 100005 http://www.cepp.sgcc.com.cn）

北京市同江印刷厂印刷

各地新华书店经售

*

2012 年 1 月第一版 2012 年 1 月北京第一次印刷

787 毫米×1092 毫米 16 开本 9 印张 216 千字

定价 **18.00** 元

前言

在长期化学专业英语教学的过程中，编者深感电厂化学英文方面资料的匮乏，电力系统同行对于电厂化学专业英语的需求也越来越迫切。长沙理工大学与电力行业产、学、研合作50余年，该校应用化学专业的电力化学方向更是面向火/核电厂及电力系统培养人才。为此，该校联合东北电力大学、上海电力学院，结合已经有的教学资料在电力系统同行的大力支持下，编写了本书。

本书由长沙理工大学李宇春教授、东北电力大学张瑛洁教授、长沙理工大学高级实验师张芳、上海电力大学讲师赵晓丹编写。李宇春负责编写第1、6、7章，张瑛洁负责编写第2章，张芳负责编写第3、5章，赵晓丹负责编写第4章。本书在编写期间，得到了湖南省电力公司试验研究院周年光高工、湖北省电力公司试验研究院李善风高工、中电投重庆远达水务有限公司李锐总工、北京中电加美环境工程技术有限责任公司戴云帆高工、长沙理工大学周琼花副教授、杨晓焱博士、广东省电力公司试验研究院林木松高工、华润鲤鱼江B厂王建党高工、深圳市爱诺实业有限公司李敬业高工等同行专家提供的无私协助与大力支持，在此表示衷心的感谢。全书由电厂化学资深专家周年光高工审稿。

本书的出版得到了湖南省"应用化学"省级特色专业、长沙理工大学"电厂化学"校级精品课程的大力支持，在此表示衷心的感谢。

由于编者的水平所限，书中难免有不足之处，希望各级领导、专家及同仁们提出宝贵意见，随时将发现的问题、修改意见发至邮箱（1198768930@qq.com），以便补充修改。

编　者

2011年11月

目　录

Chapter 1 Introduction to Power Plant Chemistry

1.1 Introduction of Steam Chemistry Systems

Steam generation, whether it be for power production or industrial process use, is a complex process. A steam generation plant is filled with pumps, piping, valves, electrical wiring, instruments, and of course, one or more boilers. All must work together to generate the desired product — steam, which may range from saturated conditions at less than 0.68MPa to supercritical steam at 580℃.

The primary water systems in a steam plant include: Feedwater /boiler /afterboiler circuit, Makeup water system, Condenser cooling, Closed cooling water, Ash sluicing at coal-fired plants.

The contrasting nature between differing systems requires water of varying quality, and also requires different treatment methods. For instance, in a well-sealed, closed cooling water system, a simple corrosion inhibitor may be the only chemical needed to protect system components. In a boiler, where water temperatures can reach 330℃ or higher and steam temperatures 580℃, highly purified feedwater, dosed with carefully controlled treatment chemicals, is required if the boiler is to operate properly. Table 1-1 illustrates some of the effects that contaminants exist in boiler water systems.

Table 1-1 Common steam generating system contaminants

Compounds	Effect on Plant Equipment and Operation
Oxygen	Oxygen is often the principal corrodent in water systems. It causes pitting and failures of pipes and heat exchangers. Oxygen corrosion in boiler systems generates particulates that travel to the boiler where they precipitate and cause further problems
Calcium	Calcium can combine with a number of anions to form deposits and scales. In cooling water systems the most common deposits include calcium sulfate. These scales retard heat transfer in condensers and other heat exchangers, and may cause under-deposition corrosion. Calcium scale is even more problematic in boilers, as the high temperatures greatly accelerate deposition and corrosion mechanisms
Magnesium	Magnesium will react with carbonates and silicates to form compounds of low solubility. Magnesium salts that leak into a boiler can react at high temperatures with water to produce acid. The corrosiveness of acidic solutions is greatly increased at the high temperatures found in boilers
Silica	Silica combines with a wide variety of elements to produce silicates, or it may form deposits on its own. Silicates form tenacious deposits in cooling water systems, boiler tubes, and on turbine blades. The scales are inert to most chemical cleaning solutions with the exception of hydrofluoric acid. This is an extremely dangerous compound, and makes prevention of silica deposition even more important
Organics	Organics are usually found in surface waters and are the result of decaying vegetation or farm runoff. Organics break down in the boiler to form organic acids The resultant low pH can be quite deleterious. Organics acid and carbon dioxide produced by decomposition can carry over to steam turbines and corrode the blades. Organics may also be found in the condensate return at industrial and cogeneration facilities. These organics are usually much shorter chained than surface water organics and may require different treatments

Continued

Compounds	Effect on Plant Equipment and Operation
Suspended solids	Suspended solids, which are also generally found in surface waters, will foul makeup treatment equipment including reverse osmosis units and ion exchangers. They will also form deposits in cooling towers and cooling water heat exchangers, a process that is exacerbates by the presence of microbiological organisms
Microbes	Microbiological fouling is principally troublesome to exchanger tubes and cooling tower. The slime produced by microbiological organisms will trap silt and suspended solids, further aggravating the situation. Microbes are a leading cause of under-deposit corrosion

1.2 Main Contents of Power Plant Chemistry

The vastly different conditions between water systems, and the complexity of a steam generating system, make the chemist's job very lively. This book provides practical examples of water chemical issues and problems for steam generating systems, and illustrates techniques and methods to control chemistry. It also provides details on many of the latest trends, findings, and developments in the areas of boiler water, steam sampling, and makeup water production. Utility chemists and researchers have made many discoveries and improvements to steam generation chemistry within the last decade. A number of these have challenged traditional ideas. Some of the developments that industrial or utility steam generation personnel should be aware of include:

Boiler water treatment has undergone many changes. For years, coordinated or congruent phosphate treatment was popular for many boilers. These programs have been found to have some serious deficiencies and are being replaced with alternative phosphate programs.

Oxygenated treatment (OT), where oxygen is deliberately injected into the boiler feedwater, is becoming very popular in once-through units in the United States. OT, which was developed in Europe, has been shown to greatly reduce iron transport from the feedwater system to the boiler.

Ion exchange is no longer the only reliable method for producing high-purity water. Other techniques, such as reverse osmosis (RO) and electrodialysis, are available for this process. Often, a combination of these techniques, such as RO plus ion exchange, may be the most economical arrangement.

Diverse opinions exist regarding chemical oxygen scavenging in boiler feedwater systems. The reducing environment produced by oxygen scavengers is known to influence flow-accelerated corrosion (FAC), in which the pipe wall gradually erodes. Several catastrophic failures, some of which have caused fatalities, have occurred in recent years due to FAC. Yet, the same reducing environment greatly lowers copper dissolution and transport in those systems that have copper-alloy feedwater heaters. Hydrazine, the most common and effective oxygen scavenger for many years, is now listed as a hazardous chemical. However, alternative organic scavengers (and pH-controlling amines) can break down in boiler systems to produce organic acids and carbon dioxide, which in turn can cause corrosion of afterboiler components, including turbine blades.

Combined-cycle or cogeneration systems with heat recovery steam generators (HRSGs) have become very popular. HRSGs, however, are often designed with two or three steam generating circuits, all at different pressures. Chemical treatment requirements for the various circuits are also different and may be dependent not only upon the pressure of the circuits, but also upon the configuration of the HRSG.

These are only some of the issues addressed in this book. Research still continues on these and many other items, and our knowledge of steam generation chemistry will only improve in the future.

1.3 Chemistry Requirement for Power Plant

1.3.1 Boiler Information of Sample Plant

A 4x135MW coal based captive power plant mainly includes boiler, turbine and generator. Boiler type is DG440/13.8-II7 type Circulating Fluidized Bed Boiler (CFBB) with over high pressure DONGFANG 135MW grade and reheater, detailed information in Table 1-2.

Table 1-2 Main parameters of power plant boiler

Boiler Type: DG440/13.8-II7	BMCR	Turbine rated condition(BECR)
Maximum Steam Flow	440t/h	398t/h
Superheat Steam Outlet Temperature	540℃	540℃
Reheat Steam Outlet Temperature	540℃	540℃
Superheat Steam Outlet Pressure	13.7MPa(g)	13.7MPa(g)
Reheat Steam inlet Temperature	322℃	314℃
Reheat Steam inlet Pressure	2.65MPa (g)	2.49MPa (g)
Reheat Steam Flow	361t/h	327t/h
Feedwater Temperature	246℃	240.3℃
Ambient Air temperature	20℃	20℃

Note: Above mentioned g indicated gauge pressure.

1.3.2 Main Technical Specifications for Power Plant Turbine

Turbine type is N135-13.7/537/537-2, which model is super high pressure, intermediate reheat, single shaft line, double casings and double exhaust condensing steam turbine. Other information includes:

- Power:135MW (THA)
- Maximum power: 146.822MW (VWO conditions, back pressure 5.4kPa)
- Rated steam parameters

Fresh steam: (before HP main stop valve) 13.24MPa/535℃

Reheat steam: (before MP combined steam valve) 2.238MPa/535℃

Back pressure: 5.4 kPa (Design cooling water temperature 24℃)

- Rated fresh steam flow: 398.9t/h
- Maximum fresh steam flow: 440t/h
- Steam distribution mode: full electronic regulating (valve management)
- Rotation direction: clockwise when viewed in the direction from turbine towards generator
- Speed: 3000r/min

1.3.3 Feedwater Quality Requirement

Feedwater quality is needed in compliance with requirement of high pressure water quality in the Quality Standards of Water and Steam for Thermal Power and Steam Generating Units (GB/T 12145—1999). Detailed information can be seen in Table 1-3.

Table 1-3 Feedwater quality requirements for power plant

Parameters		Required value	
Normal continuous blowdown rate (rated load)		<0.3%～1%	
Boiler make-up water	Normal	85t/h	
	Maximum	92t/h	
Make-up water processing Mode		Two-stage demineralization.	
Feedwater quality		To be in accordance with GB12145-2008	
Silica		<20	μg/L
Total iron		<30	μg/L
Total copper		<5	μg/L
Oxygen		<7	μg/L
pH		8.8～9.3	
Oily Matter		<0.3	mg/L
Hardness		<2	μmol/L
Hydrazine		10～30	μg/L

1.3.4 Fuel Component

Design coal in this project is a kind of mixed coal consisting of 20% local lignite and 80% import coal according to the coal analysis data in contract. The granularity of coal will be less than 200mm. The coal analysis data is as following Table 1-4.

Table 1-4 Coal analysis data for power plant fuel

Item	Symbol	Unit	Performance	Import coal	Local lignite
Sulfur as received	S_{ar}	%	1.53	0.91	4
Hydrogen as received	H_{ar}	%	3.84	4.18	2.47

Continued

Item	Symbol	Unit	Performance	Import coal	Local lignite
Carbon as received	C_{ar}	%	56.05	63.23	27.31
Nitrogen as received	N_{ar}	%	1.25	1.44	0.46
Oxygen as received	O_{ar}	%	7.34	6.23	11.76
Ash as received	A_{ar}	%	18.4	15	32
Moisture as received	M_{ar}	%	11.6	9	22
Volatile matter as dry and ash free	V_{daf}	%	29.8	31	25
Low heating value as received	$Q_{ar,net}$	kJ/kg	22,273	25,120	10,886
Coal Size Distribution: d_{max}=9mm; D_{50}=1.8mm					

1.3.5 Nature Conditions

Nature conditions for sample power plant can be seen in Tabel 1-5. Raw water is from ××× canal river, its qualities are listed in Table 1-6.

Table 1-5 **Nature conditions of power plant**

Items		Value
maximum temperature		38.8℃
minimum temperature		−11.5℃
Mean annual relative humidity		72%
wind speed	Mean annual	4.6m/s
	Winter mean	5.4m/s
	Summer mean	3.3m/s
Occur once every 30 years		38.7m/s
Seismic zone in turkey		I
Seismic Intensity		Grade 6
Field Classification		Grade II

Table 1-6 **Raw water condition of power plant**

No.	Components	Unit	Value
1	Suspended solid	ppm	26
2	pH	—	7.56
3	TDS	ppm	112
4	Ca^{2+}	ppm	64
5	Mg^{2+}	ppm	44
6	Na^{+}	ppm	39
7	S^{2-}	ppm	9.4
8	Cl^{-}	ppm	24
9	SiO_2	ppm	7
10	Alkalinity	ppm	110

1.3.6 Steam Requirement for Power Plant

Check oil quality according to schedule, periodically clean oil filter, ensure qualification of oil quality and cleanness, otherwise, new oil should be replaced with and ensure the normal and stable oil temperature and pressure.

Check the quality of steam and water according to schedule. Under normal work condition, the steam and water quality of the unit should conform following requirements. The quality of saturated and superheat steam should conform to the stipulation in Table 1-7. Quality of condensate should conform to the stipulation in Table 1-8. Steam and water system for power plant can be seen in Fig.1-1.

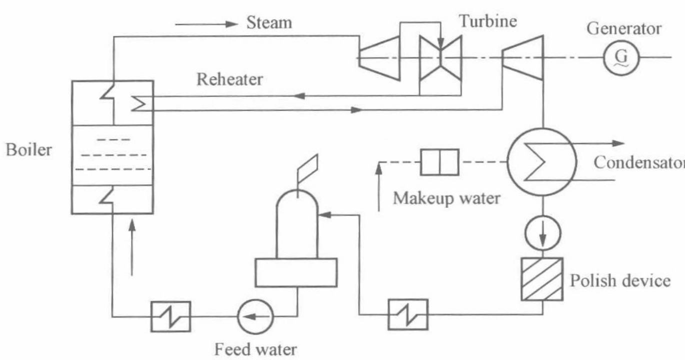

Fig.1-1 Steam and water system for captive power plant

Table 1-7 Requirements of steams for power plant

Conductivity(25℃) (μS/cm)	Sodium (μg/kg)	Carbon dioxide (μg/kg)	Iron (μg/kg)	Copper (μg/kg)
≤0.3	≤10	≤20	≤20	≤5

Table 1-8 Quality of condensate for power plant

Hardness (μmol/L)	Dissolved Oxygen (μg/L)	Conductivity (after hydrogen ion exchange) 25℃(μS/cm)	Silica dioxide (μg/L)
≤2.0	≤50	≤0.3	Should guarantee boiler water in conformity with standard

1.4 Feedwater and Boiler Water Treatment

1.4.1 Feedwater Treatment

Feedwater and boiler water samples must be inspected to meet desired water quality requirement. The quality of feedwater should be in compliance with the high pressure water quality specified by GB 12145—2008 "Water and Steam Standard for Thermal Power and Steam Power Generating Equipment". Generally, boiler vendor shall not be held responsible for damage due to corrosion or formation of scale or deposits or caustic embrittlement caused by chemical conditions of the water. Sludge accumulations in tubes will impair heat transfer and result in overheating and will affect boiler performance.

1.4.2 Water Chemistry and Steam Purity

Assure that the desired boiler water salt concentration and chemistry are maintained. Improper boiler water can lead to fouling or corrosion of internal surfaces, reducing the efficiency of the unit and possibly resulting in overheating of tubes, which would lead to tube failure.

Assure that moisture carryover from the drum is within permissible limits. For operation within design condition, the steam separation equipment will keep salt carryover within acceptable limits. Moisture carried over can include salt and other impurities which may deposit on surfaces downstream of the boiler.

The operation of the continuous blowdown valves should be determined by monitoring the boiler water chemistry. Use of these valves will increase input to the boiler for a given output. Note that drain valves on the lower waterwall headers should never be used for blowdown purposes when the unit is in operation.

Chapter 2 High-Purity Makeup Water Treatment

2.1 Introduction

As the preceding chapters have indicated, the water supplied to a steam generating unit must be pure in order to prevent serious corrosion or scaling. Ion exchange had been the backbone of the high-purity water treatment industry, but with the improvement of membrane technologies, a variety of methods now exist to produce pure water. In most cases, some form of pretreatment is needed ahead of the makeup system to protect it from fouling, scaling, or microbiological contamination.

Makeup water treatments consist of pretreatment and deionization treatment, Fig. 2-1 shows flow chart of whole treatment. The former mainly focuses on removal of turbidity, suspended solids and part of organics. The latter is mainly concerned with depth ion removal. Pretreatments include clarification and filtration; treatment devices are clarifier and filter correspondingly. Deionization treatments include cation ion exchanger, anion exchanger and mixed-bed exchanger.

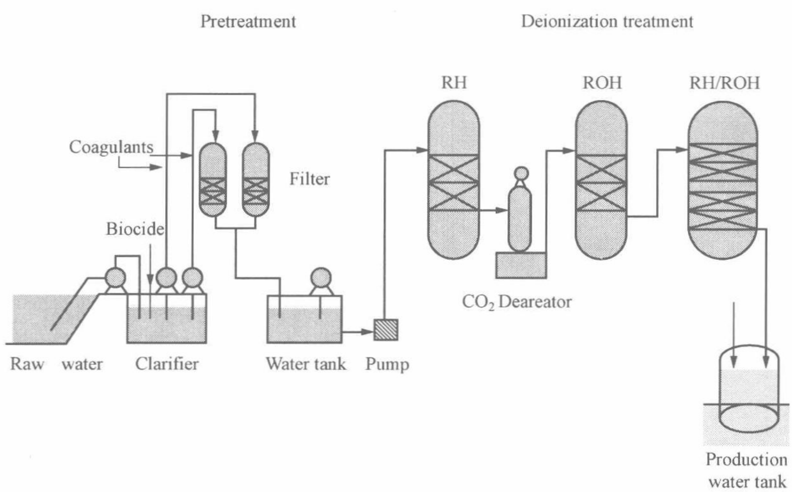

Fig. 2-1 Flow chart of makeup water treatment

2.2 Pretreatment

Water has been called the closest thing to a universal solvent, because it will dissolve, at least to some extent, most compounds. Raw waters, surface waters in particular, also contain suspended solids, including colloidal particles, microorganisms, and organic complexes. These compounds and suspended solids will cause problems in high-purity treatment systems, and must be removed or reduced before final purification. While an in-depth examination of pretreatment methods is outside the scope of this book, an overview of these techniques reveals their capabilities.

Fig. 2-1 shows a flow schematic of a common pretreatment process; each provides a very important function. The methods outlined in this scheme are:

- Microbicide feed
- Clarification/softening
- Media filtration
- Activated carbon filtration

2.2.1 Microbicide Feed

Chlorine has been the principle microbiological control agent for many years, and has proven to be the most economical biocide. However, use of chlorine gas has been curtailed due to safety and environmental concerns. Popular replacement feed chemicals now include sodium hypochlorite (liquid chlorine), bromine, chlorine dioxide, and in some cases ozone. (UV light is also a possibility). The mechanisms by which chlorine and other oxidizing agents disinfect water are described in documents. The oxidizing should be added in great enough strength to maintain a slight residual (0.1 to 0.5 ppm) throughout the pretreatment process. This helps prevent the growth of microbes in equipment downstream of the injection point. Chlorine and other oxidants will attack ion exchange resins and some type of reverse osmosis membranes, making it necessary to remove the oxidant ahead of these devices. Activated carbon is an excellent chlorine scavenger, but if the system contains no carbon filters, some other method of oxidant removal is required. Most commonly, a dehalogenating or reducing agent (sodium sulfite or sodium bisulfite) is injected ahead of the demineralizer or reverse osmosis unit to protect the equipment. The following is introduction of mechanisms and methods of disinfectants in detail.

Disinfection is a process used in water or wastewater treatment to reduce pathogens (disease-producing microorganisms) to an acceptable level. Disinfection is not the same as sterilization. Sterilization implies the destruction of all living organisms, whereas disinfection is used to destroy only the disease-causing microorganisms. Drinking water contains a large variety of microorganisms which play important role in our digestive system. So drinking water need not be sterile. Three categories of human enteric pathogens are normally of consequence: *bacteria*, *viruses*, and *amoebic cysts*. Purposeful disinfection must be capable of destroying all of the three pathogens.

The agents used for disinfection purpose are called disinfectants. To be of practical service, such water disinfectants must possess the following properties:

(1) They must destroy the kinds and numbers of pathogens that may be introduced into water within a practicable period of time over an excepted range in water temperature.

(2) They must meet possible fluctuation in composition, concentration, and condition of

the waters or wastewaters to be treated.

(3) They must be neither toxic to human and domestic animals nor unpalatable or otherwise objectionable in required concentrations.

(4) They must be dispensable at reasonable cost and safe and easy to store, transport, handle, and apply.

(5) Their strength or concentration in the treated water must be determined easily, quickly, and (preferably) automatically.

(6) They must persist within disinfected water in a sufficient concentration to provide reasonable residual protection against its possible recontamination before use, or-because this is not a normally attainable property-the disappearance of residuals must be a warning that recontamination may have taken place.

Type of Disinfectants and Utilization

Disinfection is most commonly accomplished by the use of (1) chemical agents, (2) physical agents, (3) mechanical means, and (4) radiation. Each of these techniques is considered in the following discussion.

(1) Chemical agents

Chemical agents that have been used as disinfectants include: (a) chlorine and its compounds, (b) bromine, (c) iodine, (d) ozone, (e) phenol and phenolic compounds, (f) alcohols, (g) heavy metals and related compounds, (h) dyes, (i) soaps and synthetic detergents, (j) quaternary ammonium compounds, (k) hydrogen peroxide, and, (l) various alkalies and acids.

Of these, the most common disinfectants are the oxidizing chemicals, and chlorine is the one most universally used. Bromine and iodine have also been used for wastewater disinfection. Ozone is a highly effective disinfectant, and its use is increasing even though it leaves no residual. Highly acidic or alkaline water can also be used to destroy pathogenic bacteria, because water with a pH greater than 11 or less than 3 is relatively toxic to most bacteria.

(2) Physical agents

Physical disinfectants that can be used are (a) heat and (b) light.

(a) Heat: heating water to the boiling point, for example, will destroy the major disease-producing nonspore-forming bacteria. Heat is commonly used in beverage and dairy industry, but it is not feasible means of disinfecting large quantities of wastewater because of the high cost.

(b) Light: sunlight is also a good disinfectant. In particular, ultraviolet (UV) radiation can be used. Special lamps that emit ultraviolet rays have been used successfully to sterilize small quantities of water. The efficiency of the process depends on the penetration of the rays into water. The contact geometry between the ultraviolet-light source and the water is extremely important because suspended matter , dissolved organic molecules, and water itself, as well as the microorganisms, will absorb the radiation. It is therefore difficult to use ultraviolet radiation in aqueous systems, especially when large amounts of particulate matter are present.

(3) Mechanical means

Bacteria and other organisms are also removed by mechanical means during wastewater treatment, e.g. sedimentation, grit chamber, activated sludge, screening etc.

(4) Radiation

The major types of radiation are electromagnetic, acoustic, and particle. Gamma rays are emitted from radioisotopes, such as cobalt 60. Because of their penetration power, gamma rays have been used to disinfect (sterilize) both water and wastewater.

Mechanisms of Disinfectants

The following four mechanisms have been proposed to explain the action of disinfectants:

(1) Damage to the cell wall

Damage or destruction of the cell wall will result in cell lysis and death. Some agents, such as penicillin, inhibit the synthesis of the bacterial cell wall.

(2) Alteration of cell permeability

Agents such ad phenolic compounds and detergents alter the permeability of the cytoplasmic membrane. These substances destroy the selective permeability of the membrane and allow vital nutrients, such as nitrogen and phosphorus, to escape.

(3)Alteration of the colloidal nature of the protoplasm

Heat, radiation, and highly acidic or alkaline agents alter the colloidal nature of the protoplasm. Heat will coagulate the cell protein and acids or bases will denature proteins, producing a lethal effect.

(4)Inhibition of enzyme activity

Oxidizing agents, such as chlorine, can alter the chemical arrangement of enzymes and deactivate the enzymes.

Factors Influencing the Action of Disinfectants

In applying the disinfection agents or means that have been described, the following factors must be considered: (1) contact time,(2) concentration and type of chemical agent, (3) intensity and nature of physical agent,(4) temperature, (5) number of organisms,(6) types of organisms, and (7) nature of suspending liquid.

Disinfection Operation with Several Important Disinfectants

Disinfection with chlorine (Cl_2) and chlorine compounds

As noted earlier, of all the chemical disinfectants, chlorine is perhaps the one most commonly used throughout the world.

The most common chlorine compounds used in wastewater treatment plants are chlorine gas (Cl_2), calcium hypochlorite [$Ca(OCl)_2$], sodium hypochlorite (NaOCl), and chlorine dioxide (ClO_2). Calcium and sodium hypochlorite are most often used in very small treatment plants, such as package plants, where simplicity and safety are far more important than cost. Sodium hypochlorite is often used at large facilities, primarily for reasons of safety as influenced by local conditions. Because chlorine dioxide has some unusual properties (it does