

The maintenance of files of information has little purpose unless they are available for ready reference and record experience in a form which can be used as a guide to the solving of current problems. Records represent condensed information; they should be systematically kept and regularly filed, to be referred to as needed.

Forms

The type and complexity of record forms required depend on the size and character of a treatment plant. Thus simple forms may be adequate for a chlorination plant treating a well supply: they will provide space for recording the time of starting and stopping pumps, readings of the kilowatt-hour meter, volume of water treated, indicated chlorine dose, loss in weight of chlorine cylinder—i.e., the amount of chlorine compound used (actual dose)—concentration of residual chlorine as determined at specified intervals, and a remarks column for recording pertinent events or observations. These data may be recorded on two forms, one dealing with pump operation and the other with chlorination, especially when pumps are engine-driven and records of consumption of fuel, lubricating oil, etc. are needed.

By contrast very extensive records must be kept at large lime-soda-softening plants where fluoridation is carried out and where laboratory control is available. Under these circumstances shift operators should keep individual records of the various chemical doses, volume of water treated, etc. at hourly intervals, on forms suitable for an 8-hour-shift period or a 24-hour period. The information recorded on these working forms should be transcribed daily on to daily summarizing forms. The chief operator or chemist would also use special forms for records of laboratory tests, which would include volume of each specific sample examined, volume of reagents used and the computations involved, so that the work may be rechecked later if the results are found to be inconsistent. An

example of the laboratory work sheet is that for microscopic examinations shown in Fig. 22 (page 356). The daily summary of all the pertinent data should be on forms having 31 horizontal lines, so that one form will cover a period of one month. Space should be provided for a monthly summary of totals, maximum and minimum values and computed monthly averages.

Many treatment plants are more complex than chlorination installations but yet less comprehensive in processes involved than large softening plants. Fig. 15 shows a typical form used at filtration plants where daily records on forms designed for a period of one month are adequate. This form includes space for laboratory results representing plant performance, i.e., the results achieved by the use of the chemical doses and operating data recorded. A plant log should also be kept so that casual daily events and observations may be noted for future guidance. For instance, water temperature, as influenced by meteorological conditions, may be observed to affect coagulation or the washing of filters, and study of such observations may disclose trends which can be useful guides in future operation.

An often-neglected aspect of records is the systematic notation of information on maintenance and repair of equipment. Protective maintenance should be organized according to instruction manuals for specific equipment, and routine work should be recorded. For example, a chemical feeder should be checked for lubrication and functioning characteristics each day, shut down for cleaning and adjusting on a weekly basis, and given an overhaul for replacement of worn parts on a semi-annual or annual basis. Pertinent records of such protective maintenance will serve as a reminder of the need for such periodic checking to forestall the postponement of repairs with the risk of failure of equipment.

Files

One of the surprisingly frequent deficiencies encountered at treatment plants is the absence of a set of construction plans and specifications applying to the plant *as built*, together with catalogues and instruction manuals for the equipment. These are essential to the economical operation and maintenance of any plant, especially the more elaborate equipment at large filtration and softening plants. The design and construction engineers should be required to furnish at least two complete sets of plans and specifications, one to be filed in the central office and the other at the treatment plant. Operators should study these so that they know the location, characteristics and functions of all equipment. Colour coding should be used to indicate the nature of piping, conduits, electric wiring, etc. in treatment plants, for guidance in repairs and maintenance.

Although there is no substitute for ability and experience, the realities of life often necessitate compromise. The need for well-trained staffs may be greatest just where funds and facilities are scarcest, as where water resources are so limited that a heavily polluted and mineralized water must be used in spite of the cost and complexity of treatment. No hard-and-fast rules can be laid down, therefore, as to operating personnel, but certain procedures can assist in ensuring the adequacy of personnel for the operation and control of treatment plants.

Qualifications of operators

Many epidemics of water-borne diseases in the past were traceable to faulty operation (due in large part to poor training of operators or to individual neglect of duty) rather than to inadequate equipment. One factor in the situation was often the appointment of operators for political motives rather than for ability. In the United States this led to the organized training of operators and the establishment of minimum qualifications for operators of specific types and sizes of plant, so that trained and experienced operators could not be replaced by unqualified persons, and all qualified operators would have the incentive of advancement. These programmes, however, cannot be applied on a world-wide basis. Minimum qualifications must be considered in the light of budgetary realities and the supply of trained personnel.

The operator in charge of a plant should be technically skilled and experienced. The desirable qualifications may be summarized as those of a good manager, familiar with hydraulics as applied to waterworks and with the principles of physics, chemistry and biology underlying water-treatment processes as well as the public health objectives of delivering attractive water of safe, sanitary quality to the consumer. Ideally a sanitary engineer should be employed for this position, but in many parts of the world this ideal cannot be reached because of the shortage of sanitary engineers or

because salary scales are too low to attract engineers to such positions. Therefore the ultimate responsibility for technical supervision frequently has to be assigned to the waterworks superintendent or chief engineer or to a consultant. The employment of a consultant has the advantage of making available the services of a specialist to a number of plants when they are located close enough together to make the travelling practical.

In practice the qualifications of chief operators cover a wide range—from technically trained superintendents of filtration to skilled mechanics. When the latter work under the general supervision of someone with technical training, the experience, innate ability and integrity of the operator are more important than formal training. The qualifications of shift operators at large plants should be the same as those of chief operators but with less experience required, so that experience will eventually qualify them for advancement.

Considering the need to grasp the principles of technical subjects and their application, the minimum education qualification for chief operators of small plants or for shift operators of large plants would appear to be a secondary school education. The realistic approach to this question is based not so much on consideration of the subjects taught in secondary schools but rather on the fact that completion of secondary school testifies to a certain ability to study and learn, as well as to the character and status associated with continuing in school for the time required.

Because opportunities to gain specific experience in a subordinate post at a water-treatment plant are rare, it is impossible to standardize the previous experience required for operators. Their experience qualifications must often be judged in terms of previous occupation and aptitude for skills similar to those called for in water-treatment plants.

The task of training operators becomes all the more important when the desirable technical qualifications cannot be met. Training may be subdivided into (a) in-service training of operators at specific plants in the course of their routine duties and (b) short courses given at some centrally located large treatment plant, where operators from a region may gather for more formal instruction, supplemented by demonstrations and field work.

In-service training of operators

The success of any in-service training programme depends on many factors. Especially at large plants, a chain of command must first be established, so that each member of the staff will be supervised by a superior who is recognized as such and hence is respected. Until this respect is gained, instruction and suggestions will not be received in the right spirit, and resentment may destroy the open-minded attitude necessary for learning. Once respect is gained, however, each daily order or suggestion can be given by a superior in a manner which explains its objective or purpose, the

principles underlying the equipment or process involved, etc. until the subordinate has mastered the details.

Second, a more formal, organized programme is necessary to provide basic explanation of complex equipment or processes. For instance, the whole subject of chlorination could be covered in a series of discussions of the points dealt with in Chapter 8 as exemplified in the chlorination practice actually followed in the specific plant: the discussion of chlorine cylinders and the properties of chlorine gas, for instance, would use the diagrams of cylinders, valves, etc. which should have accompanied the equipment from the manufacturers. This type of instruction would be followed at intervals until the whole treatment plant had been covered.

Third, the operators and subordinate personnel should be helped to improve their powers of observation by having their attention drawn to examples in the plant; for instance, the character of floc during periods of relatively poor flocculation would be compared with good or standard floc. Even relatively unimportant details such as hard-opening valves may be used to demonstrate the effect of poor maintenance. Such in-service training should aim at increasing awareness of the appearance, "feel", sound, odour, etc. of the plant when functioning normally, so that abnormal events will be noted at once and corrective action taken.

Fourth, the orthotolidine test made by shift operators should be used as the introduction to other plant-control tests in the laboratory. The approach here should be to expand the range of "tools" available to each operator, so that he will recognize the measurement of, for example, residual-chlorine content or of pH value as similar in nature and purpose to the measurement of water pressure by a gauge or of volume by a meter. This training should include the actual use of laboratory results in the control of the plant.

The fifth aspect of in-service training should embrace organized reading of catalogues, manuals and any other available literature. This requires the acknowledgement by the supervisor that reading by a subordinate while on duty is not neglect of duty but rather a good use of spare time, which should be available at well-functioning plants during periods when major repairs are not needed and normal chemical doses are satisfactory. Regularity in the performance of duties will create time for minor activities and also periods when an operator may study. Such study must be rewarded, however, otherwise spare time will be wasted or else will cease to be available because of a more indolent performance of duty.

Number of operators

The number of operators needed at treatment plants depends on many factors. Chlorinated supplies from wells may be operated by one person, responsible for operation and maintenance, who will visit the plants several times each day to check the pumps and chlorinators. Under these circum-

stances the motors should be equipped with an overload switch and the chlorinators should be semi-automatic, that is, they should start and stop automatically when the motors start and stop. Since the chlorine doses required for most well waters are rather constant, continuous supervision is not needed, so the operator can be assigned other duties. In fact, many small supplies of this type are supervised and operated by one operator, who reads meters and otherwise acts as superintendent of water. Part-time labour may be employed for distribution-system repairs under proper supervision, to relieve the scarce experienced personnel of this work.

Another type of plant that is simple to operate is that for zeolite softening of hard well supplies, with or without chlorination. Usually the hardness of well waters varies only on a seasonal basis, if at all, and the zeolite units may be of the automatic type, where the regeneration cycle is controlled by a water meter after a specified volume of water has been softened. Manually controlled zeolite units require the operator to be in attendance at least one hour per regeneration per unit; usually two units are used, so about three hours attendance per day is needed for effective operation of such units.

A note of caution is pertinent here. While automatic units save in labour, they require more intelligent maintenance of the equipment than the simpler, manually controlled units.

Small filtration plants treating water from impounding reservoirs are often relatively easy to supervise, because the turbidity and colour of stored waters do not fluctuate rapidly. Coagulant doses may be adjusted and filters washed every 24 hours, and a well-established routine will permit operators to devote time to other duties. All plants operated on a part-time basis, however, should be equipped with automatic shut-off switches on motors of pumps, chemical feeders and chlorinators. One common procedure, where both low-lift and high-lift pumps are used, is to control the low-lift pumps by float switches in the clear wells or filtered-water reservoirs and to control the high-lift pumps by water-pressure switches on the discharge mains; a minimum-level float shut-off in the clear well is also provided to stop the high-lift pumps if necessary. In this way the high-lift pumps are shut down automatically when the distribution-system pressure reaches a selected point, but the plants continue to operate until the clear wells are filled, at which point the pumps, chemical feeders and chlorinators are shut down automatically. One important precaution, however, is that with such control the plant must be started manually so that the operator can select the chemical doses and check performance at the start of operation each day.

Semi-automatic control of supplies flowing by gravity requires that a very reliable source of electricity be available, because water will continue to flow during periods of power failure while motor-driven chemical feeders will stop operating. This is especially important when chlorination is provided by gas chlorinators, with motor-driven pumps to furnish water

under pressure for the ejectors, or when motor-driven hypochlorinators are used. Water-driven hypochlorinators are available for use where electric current is not available or is not reliable. Signal lights or bells are desirable to disclose failure of electric power, if an operator is not in constant attendance.

At more complicated treatment plants in continuous operation the minimum number of operators is considered to be four: the chief operator and three shift operators. They should be assisted as needed by maintenance mechanics and labourers.

At very large plants with associated pumping plants, where separate groups are employed in the pumping station, chemical building, filter-operating floor, laboratory, etc., the ideal is to have four operators for each group, supervised by a plant superintendent; this allows a relief for the three shift operators in each group. Several maintenance mechanics and labourers will also be needed.

Specific duties and instructions

Operating manuals are frequently complex, so simplified directions and orders should be typed and displayed at appropriate points for the guidance of shift operators. In the same way, protective maintenance programmes should be established in the form of orders, so that specified procedures will be placed on a routine orderly basis. One method is to have the various procedures pertaining to each type of equipment tabulated on check-lists, specifying the frequency of the performance of each listed activity, on which the operator inserts the time and date when the procedure was carried out. For instance, the delivery capacity of a chemical feeder might be checked every week, but the lubrication and proper functioning of the unit would be checked at each shift.

General

The basic consideration in regard to personnel is that the health of the consumers and the proper maintenance and operation of costly treatment plants rest upon the ability and adequacy of the operating staff. The functioning of treatment plants depends largely on the character of supervision and control, so investments in structures are not warranted unless the quality of the maintenance and operation provided enables them to function properly and economically.

The quality of potable water served to the public is the concern of both water and health officials. There should therefore be close co-operation between the two groups; small plants especially may need to draw on the technical resources of the health department. In this connection it may be noted here that operating personnel should be given health checks, especially to determine whether they are carriers of typhoid fever. When the raw water is heavily polluted they should be vaccinated against typhoid (also cholera when appropriate).

CHAPTER 16

OPERATION OF DISTRIBUTION SYSTEMS

Because the treatment processes discussed in this monograph have a direct bearing on the supervision and operation of distribution systems, a few related points are reviewed here.

Continuous service

The very unfortunate practice of supplying water for only a portion of each day, because of shortage of water, creates a serious menace to the health of consumers, as well as inconvenience. The zero or negative pressure produced by this practice leads to the entrance of pollution by seepage from nearby sewers, cesspools, etc., because no system is watertight, especially one that has been in use for many years. In areas of limited economic resources a choice must often be made between continuous service to a restricted number of people and intermittent service to a larger number of people. The trend is to favour the first alternative.

Cross-connexions

No direct connexion should be made between the piping of distribution systems and non-potable water supplies, sewers or industrial-plant tanks used to store polluted water, acids or the like. Blow-off drains, intended to dewater distribution systems, should terminate above the level of any nearby surface waters; they should never be connected to sewers.

Modern plumbing fixtures, with provisions against back-siphonage of sewage, are not available in many areas, but every effort should be made to encourage the enactment and enforcement of modern plumbing codes.

Dead-end mains

Many distribution systems have extensions around the periphery, usually not connected to other extensions. These dead ends prevent the free circulation of the water, which in turn imposes hydraulic restrictions

to the flow of water. Without free circulation of water, residual chlorine cannot be maintained throughout a system and conditions are favourable for the reduction of sulfates to taste-producing sulfides and for corrosion of the mains. The policy should therefore be to avoid dead-end mains and to make a practice of flushing all such existing mains through hydrants at routine intervals.

Open reservoirs and tanks

It is not economically feasible to cover many equalizing reservoirs, because of their size, but tanks should be covered to prevent the entrance of dust, birds, and also sunlight, the latter to prevent the growth of algae. Many covered tanks have ventilating openings. These are not needed, because there is no significant aeration of water in quiescent storage, and in any case no covered tank is airtight.

The only exception is when ground water is aerated by spraying it into the air above the maximum water level of a tank, when air circulation is necessary. This method of aeration is attractive because it avoids double-pumping. Openings for aeration purposes should be screened to exclude birds and shaded to minimize the intensity of the light reaching the water.

Maintaining quality of water in distribution systems

The quality of water reaching the homes of consumers depends on the supervision, maintenance, operation and laboratory control of the whole supply, including the distribution system. Samples of water must be collected at appropriate points on a system to disclose the physical, chemical and bacteriological quality and hence the effectiveness of treatment. Samples collected at well-selected sampling points will disclose any localized deterioration in quality, due, for instance, to secondary pollution through cross-connexions, or to backflow from tanks and reservoirs, or to biochemical changes in the water standing in dead-end mains.

New or repaired mains should be chlorinated, including the packing material used at joints. The inner surface of piping exposed during repairs should be inspected to check the effectiveness of corrosion-prevention measures and the presence of slime organisms, or iron and manganese deposits, or after-precipitation of alum floc in the mains following the passage of improperly flocculated alum through the filters.

In summary, the distribution system is the testing ground for the effectiveness of all the supervision, operation and control being exercised from the source of supply to the consumer's tap.

ANNEXES

Annex 1

COMPUTATION OF SOLUTIONS AND DOSES

Strength of solutions

Recommended strength of solution for application to water supplies is given in grams of chemical per litre of solution (or lb/gal), i.e., the weight of chemical in a specified volume of solution. If a solution of 50 g/l (or say 0.5 lb/gal) is used, it is obvious almost without computation that 5 kg would be added to sufficient water to make up 100 l (or, say, 50 lb made up to 100 gal) of solution. Then if the chemical dose is to be 15 kg/h, $15/5 \times 100$, or 300 l of the solution would be added per hour; for 15 lb/h, the amount would be $15/50 \times 100$, or 30 gal.

Contrast this with the complexity introduced when strength of solution is given as a percentage. Suppose a 5% solution is to be used. This is not a solution of 5 parts chemical to 100 parts water, by weight, but rather 5 parts of chemical to 95 parts of water to give 100 parts (by weight) of solution. Were the procedure followed of adding 100 parts of water, the solution would have a strength of $5/(100 + 5)$, or 0.0476 or 4.76%. Even a correctly made 5% solution would contain an awkward amount (about 52.7 g/l) of chemical in solution.

For these reasons the strength of solution usually is not given as a percentage in this monograph. If, however, it should be necessary to prepare a solution of a certain strength given in percentage, the simplest way is to subtract the weight of chemical from 100 units of weight and to add that weight of water. For example, a 7% solution requires 7 kg (or lb) chemical, and $100 - 7$, or 93 kg (or lb) water. To make up this solution 93 litres (93 kg) of water would be added for each 7 kg of chemical ($93/10 = 9.3$ UK gal/7 lb; $93/8.34 = 11.1$ US gal/7 lb).

The formula for computing per cent strength of solution is as follows:

$$\text{Per cent strength of solution} = 100 \times \frac{\text{wt. of chemical}}{\text{wt. of chemical} + \text{wt. of water}}$$

Table 25 shows the weight of chemical per unit volume of solution for three commonly used waterworks chemicals.

TABLE 25
WEIGHT OF CHEMICAL PER UNIT VOLUME FOR VARIOUS PER CENT SOLUTIONS

% solution	Alum (Al ₂ (SO ₄) ₃)			Soda ash (Na ₂ CO ₃)			Salt (NaCl)			Calcium chloride (CaCl ₂)		
	g/l	lb/gal UK	lb/gal US	g/l	lb/gal UK	lb/gal US	g/l	lb/gal UK	lb/gal US	g/l	lb/gal UK	lb/gal US
1	10.09	0.1009	0.0842	10.09	0.1009	0.0842	10.05	0.1005	0.0839	10.06	0.1006	0.0840
2	20.39	0.2039	0.1702	20.38	0.2038	0.1701	20.25	0.2025	0.1690	20.30	0.2030	0.1694
4	41.62	0.4162	0.3473	41.59	0.4159	0.3471	41.07	0.4107	0.3428	41.26	0.4126	0.3444
6	63.71	0.6371	0.5317	63.64	0.6364	0.5311	62.48	0.6248	0.5214	62.92	0.6292	0.5251
8	86.70	0.8670	0.7235	86.53	0.8653	0.7221	84.47	0.8447	0.7049	85.27	0.8527	0.7116
10	110.6	1.106	0.9232	110.3	1.103	0.9204	107.1	1.071	0.8935	108.4	1.084	0.9042
12	135.5	1.355	1.131	134.9	1.349	1.126	130.3	1.303	1.087	132.2	1.322	1.103
14	161.4	1.614	1.347	160.5	1.605	1.339	154.1	1.541	1.286	156.8	1.568	1.308
16	188.3	1.883	1.572				178.6	1.786	1.490	182.2	1.822	1.520

Mixing of solutions of the same chemical but of different strengths is simple when strength is expressed as unit weight per unit volume. For instance, suppose that a 50-l tank contains 20 l solution with a strength of 100 g/l and it is desired to prepare 50 l solution containing 200 g/l. Then:

$$\begin{aligned}
 50 \times 200 &= 10\,000 \text{ g} = 10 \text{ kg needed} \\
 20 \times 100 &= 2\,000 \text{ g} = \underline{2 \text{ kg available}} \\
 &8 \text{ kg to be added}
 \end{aligned}$$

Then 8 kg chemical would be added to the tank and enough water to fill it.

When solutions are expressed as per cent strength, the same method of total weights is used, but the weight of the chemical must first be computed from the per cent strength. For example, a 100-l tank contains 15 litres 3% solution of Na₂CO₃ and is to be filled with a 4% solution. Then, using the values shown in Table 25, the computation would be as follows:

$$\begin{aligned}
 4\% \text{ solution} &= 41.59 \text{ g/l} \\
 3\% \text{ solution (by interpolation)} &= 30.98 \text{ g/l} \\
 41.6 \times 100 &= 4160 \text{ g needed} \\
 31.0 \times 15 &= \underline{465 \text{ g available}} \\
 &3695 \text{ g to be added}
 \end{aligned}$$

Therefore 3695 g, or 3.7 kg, sodium carbonate would be added to the 15 l in the tank, and sufficient water to make 100 l when the chemical is dissolved.

Chemical doses

The following are convenient formulae for computing chemical doses:

1. Pounds per million gallons $= \frac{\text{lb of chemical}}{\text{millions of gallons of water}}$

2. Parts per million $= \frac{\text{grams of chemical}}{\text{cubic meters of water}}$
 $= \frac{\text{lb of chemical}}{\text{millions of pounds of water}}$
 $= \frac{\text{lb of chemical}}{10 \times \text{millions of UK gallons of water}}$
 $= \frac{\text{lb of chemical}}{8.34 \times \text{millions of US gallons of water}}$

3. Wt. of chemical per day $= \frac{\text{p.p.m.} \times \text{wt. of water treated in 1 day}}{1 \text{ million}}$
 grams $= \text{p.p.m.} \times \text{m}^3 \text{ treated in 1 day}$
 pounds $= \frac{\text{p.p.m.} \times \text{UK gal treated in 1 day} \times 10}{1 \text{ million}}$
 $= \frac{\text{p.p.m.} \times \text{US gal treated in 1 day} \times 8.34}{1 \text{ million}}$

Examples :

When 340 lb chemical is added to 1.5 million US gal water, the dose is (by formula 2) $340/(1.5 \times 8.34) = 27.2$ p.p.m.

A dose of 4.2 p.p.m. for 0.78 m.g.d. US (780 000 US gal/24 h) requires (by formula 3) the application of $4.2 \times 780\,000 \times 8.34/1\,000\,000 = 27.3$ lb chemical per 24 h.

Annex 2
PROPERTIES OF CHEMICALS USED IN WATER TREATMENT

Chemical name and formula	Common or trade name	Shipping containers	Suitable handling materials	Available forms	Weight, lb/ft ³	Solubility, lb/gal US	Commercial strength	Characteristics
Activated carbon C	Aqua Nuchar, Hydrocharco, Norite	bags, bulk	dry: iron, steel; wet: rubber, silicon iron, stainless steel	black granular powder	15	insoluble (suspension used)		
Alum (see Aluminium sulfate)								
Aluminium sulfate $Al_2(SO_4)_3 \cdot 14H_2O$	alum, filter alum, sulfate of alumina	100-200-lb bags, 300-400-lb barrels, bulk (carloads)	dry: iron, steel; solution: lead, rubber, silicon iron-asphalt	ivory-coloured powder granule lump	38-45 60-63 62-67	4.2 (60°F)	15-22% Al_2O_3	pH of 1% solution: 3.4
Ammonium aluminium sulfate $Al_2(SO_4)_3 \cdot (NH_4)_2 \cdot SO_4 \cdot 24H_2O$	ammonia alum, crystal alum	bags, barrels, bulk	Duriron, lead, rubber, silicon iron, stoneware	lump nut pea powdered	64-68 62 65 60	0.3 (32°F); 8.3 (212°F)	11% Al_2O_3	pH of 1% solution: 3.5
Anhydrous ammonia NH_3	ammonia	50-, 100-, 150-lb cylinders	glass, iron, Monel metal, nickel, steel	colourless gas		3.9 (32°F); 3.1 (60°F); 1.8 (125°F)	99%-100% NH_3	
Aqua ammonia NH_4OH	ammonia water, ammonium hydrate, ammonium hydroxide	carboys, 750-lb drums, 8000-gal tank cars	glass, iron, Monel metal, nickel, steel	colourless liquid		completely soluble	29.4% NH_3 (28°Baumé)	
Bentonite	colloidal clay	100-lb bags	iron, steel	powder, pellet, mixed sizes	60	insoluble (colloidal sol. used)		
Calcite (see Calcium carbonate)								
Calcium carbonate $CaCO_3$	marble	bags or bulk	iron, steel	powder or mixed sizes				
Calcium hydroxide $Ca(OH)_2$	hydrated lime, slaked lime	50-lb bags, 100-lb barrels, bulk (carloads)	asphalt, cement, iron, rubber, steel	white powder: light dense	26-48 40-70	0.014 (68°F); 0.012 (90°F)	85%-99% $Ca(OH)_2$, 63%-73% CaO	Hopper agitation required for dry-feeding of light form

CHEMICALS USED IN WATER TREATMENT (continued)

Chemical name and formula	Common or trade name	Shipping containers	Suitable handling materials	Available forms	Weight, lb/ft ³	Solubility, lb/gal US	Commercial strength	Characteristics
Calcium hypochlorite $\text{Ca}(\text{OCl})_2 \cdot 4\text{H}_2\text{O}$	HTH, Perchloron, Pittchlor	5-lb cans; 100-, 300-, 800-lb drums	glass, rubber, stoneware, wood	white granule, powder	52.5		70% available Cl_2	1%–3% available Cl_2 solution used
Calcium oxide CaO	burnt lime, chemical lime, quicklime, unslaked lime	50-lb bags, 100-lb barrels, bulk (carloads)	asphalt, cement, iron, rubber, steel	lump pebble granule	50–65 50–70	Slakes to form hydrated lime	75%–99% CaO	pH of saturated solution: 12.4; detention time, temperature and amount of water critical for efficient slaking
Chlorinated lime $\text{CaO} \cdot 2\text{CaOCl}_2 \cdot 3\text{H}_2\text{O}$	bleaching powder, chloride of lime	100-, 300-, 800-lb drums	glass, rubber, stoneware, wood	white powder	48	Chlorine portion soluble	25%–37% available Cl_2	Deteriorates
Chlorine Cl_2	chlorine gas, liquid chlorine	100-, 150-lb cylinders; 1-ton tanks; 16-, 30-ton tank cars	dry: black iron, copper, steel; wet, gas: glass, hard rubber, silver	liquefied gas under pressure	91.7	0.07 (60°F); 0.04 (100°F)	99.8% Cl_2	
Chlorine dioxide ClO_2	chlorine dioxide	Generated as used	plastic, soft rubber (avoid hard rubber)	yellow-red gas		0.02	26.3% available Cl_2	
Copper sulfate $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	blue vitriol, bluestone	100-lb bags, 450-lb barrels, drums	asphalt, silicon iron, stainless steel	crystal lump powder	75–90 73–80 60–64	1.6 (32°F); 2.2 (68°F); 2.6 (86°F)	99% CuSO_4	
Disodium phosphate $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$	basic sodium phosphate, DSP, secondary sodium phosphate	125-lb kegs, 200-lb bags, 325-lb barrels	cast iron, steel	crystal	60–64	0.4 (32°F); 6.4 (86°F)	19%–19.5% P_2O_5	Precipitates Ca, Mg; pH of 1% solution: 9.1
Ferric chloride (a) FeCl_3 solution (b) $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ (c) FeCl_3	Ferrichlor, chloride of iron crystal ferric chloride anhydrous ferric chloride	5-, 13-gal carboys, trucks, tank cars 300-lb barrels 500-lb casks; 100-, 300-, 400-lb kegs	glass, rubber, stoneware, synthetic resins	dark-brown syrupy liquid yellow-brown lump green-black powder	60–64 85–90	completely soluble 5.0 (98°F) 4.0 (86°F)	35%–45% FeCl_3 12%–17% Fe 59%–61% FeCl_3 20%–21% Fe 98% FeCl_3 , 34% Fe	Hygroscopic (store lumps and powder in tight containers); no dry feed; optimum pH: 4–11

Ferric sulfate $\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$	Ferrifloc, Ferrisul	100-175-lb bags, 400-425-lb drums	ceramics, lead, plastic, rubber, 18-8 stainless steel	red-brown powder or granule	70-72	Soluble in 2-4 parts cold water	90%-94% $\text{Fe}_2(\text{SO}_4)_3$, 25%- 26% Fe	Mildly hygroscopic; coagulant at pH 3.5-11.0	
Ferrous sulfate $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	copperas, green vitriol	bags, barrels, bulk	asphalt, concrete, lead, tin, wood	green crystal, granule, lump	63-66	4.0 (68°F)	55% FeSO_4 , 20% Fe	Hygroscopic; cakes in storage; optimum pH: 8.5-11.0	
Fluosilicic acid H_2SiF_6	fluosilicic acid	rubber-lined drums	rubber-lined steel	liquid		approx. 1.2 (68°F)	approx. 35%		
Lime (see Calcium hydroxide and Calcium oxide)									
Potassium aluminium sulfate $\text{K}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$	potash alum	bags, barrels, bulk (carloads)	lead, lead-lined rubber, stone- ware	lump granule powder	62-67 60-65 60	0.5 (32°F); 1.0 (68°F); 1.4 (86°F)	10%-11% Al_2O_3	Low, even solubility; pH of 1% solution: 3.5	
Soda ash (see Sodium carbonate)									
Sodium aluminate $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3$	soda alum	100-150-lb bags, 250-440-lb drums, solution	iron, plastic, rubber, steel	white or green- ish-yellow crystal	50-60	3.0 (68°F); 3.3 (86°F)	55% Al_2O_3 , 35% Na_2O , 5% excess NaOH	Hopper agitation required for dry feed	
Sodium carbonate Na_2CO_3	soda ash	bags, barrels, bulk (carloads)	iron, rubber, steel	liquid (27° Baumé)	23 35 65	1.5 (68°F); 2.3 (86°F)	32% Al_2O_3 , Na_2O , 10% NaOH	Hopper agitation required for dry feed of light and extra-light forms; pH of 1% solu- tion: 11.2	
Sodium chloride NaCl	common salt	bags, barrels, carloads	bronze, cement, rubber	rock fine grains	50-60 58-70	2.9 (32°F); 3.0 (68°-86°F)	98% NaCl		
Sodium chlorite NaClO_2	technical sodium chlorite	100-lb drums	metals (avoid cellulose materials)	light-orange powder, flake	70	2.0 (68°F)	82% NaClO_2 , 30% available Cl_2	Generates ClO_2 at pH 3.0	

CHEMICALS USED IN WATER TREATMENT (concluded)

Chemical name and formula	Common or trade name	Shipping containers	Suitable handling materials	Available forms	Weight, lb/ft ³	Solubility, lb/gal US	Commercial strength	Characteristics
Sodium fluoride NaF	fluoride	bags, barrels, fibre drums, kegs	iron, lead, steel	Nile blue or white powder: light dense	50 75	0.35 (most temperatures)	90 %-95 % NaF	pH of 4 % solution: 6.6
Sodium hexametaphosphate (NaPO ₃) ₆	Calgon, glassy phosphate, vitreous phosphate	100-lb bags	hard rubber, plastic, stainless steel	crystal, flake, powder	47	1-4.2	66 % P ₂ O ₅ (unadjusted)	pH of 0.25 % solution: 6.0-8.3
Sodium hydroxide NaOH	caustic soda, soda lye	100-700-lb drums; bulk (trucks, tank cars)	cast iron, rubber, steel	flake, lump, liquid		2.4 (32°F); 4.4 (68°F); 4.8 (104°F)	98.9 % NaOH, 74 % Na ₂ O	Solid hygroscopic; pH of 1 % solution: 12.9
Sodium hypochlorite NaOCl	sodium hypochlorite	5-, 13-gal carboys; 1300-2000-gal tank trucks	ceramic, glass, plastic, rubber	light-yellow liquid			12 %-15 % available Cl ₂	
Sodium silicofluoride Na ₂ SiF ₆	sodium silicofluoride	bags, barrels, fibre drums	iron, lead, steel	Nile blue or yellowish-white powder	72	0.03 (32°F); 0.06 (72°F); 0.12 (140°F)	99 % Na ₂ SiF ₆	pH of 1 % solution: 3.5
Sodium thiosulfate Na ₂ S ₂ O ₃ · 5H ₂ O	hypo	bags, barrels, drums, kegs	cast iron, low-carbon steel, stoneware	standard crystal rice fine granule	64-65 65 70 61	6.2 (32°F)	98 %-99 % Na ₂ S ₂ O ₃	
Sulfur dioxide SO ₂	sulfur dioxide	100-, 150-, 200-lb cylinders	dry: steel	colourless gas			100 % SO ₂	
Trisodium phosphate Na ₃ PO ₄ · 12H ₂ O	normal sodium phosphate, tertiary sodium phosphate, TSP	125-lb kegs, 200-lb bags, 325-lb barrels	cast iron, steel	crystal: coarse medium standard	56 58 61	0.1 (32°F); 13.0 (158°F)	19 % P ₂ O ₅	pH of 1 % solution: 11.9

Annex 3

CONVERSION TABLES

Chemical doses

(Equivalents valid for dilute solutions whose density is very close to 1)

French degree	= 1 part per 100 000 as CaCO ₃	
	= 10 mg/l as CaCO ₃	
	= 1/5 milli-equivalent (or 1/5000 equivalent)	
Milli-equivalent	= 5 French degrees	
Milligram per litre (mg/l)	= 1 part per million (p.p.m.)	
Gram per cubic metre (g/m ³)	= 1 p.p.m.	

Conversion of fractions to decimal values

$\frac{1}{32} = 0.03125$	$\frac{1}{4} = 0.25000$	$\frac{1}{2} = 0.50000$	$\frac{3}{4} = 0.75000$
$\frac{1}{16} = 0.06250$	$\frac{9}{32} = 0.28125$	$\frac{17}{32} = 0.53125$	$\frac{7}{9} = 0.77778$
$\frac{1}{12} = 0.08333$	$\frac{5}{16} = 0.31250$	$\frac{5}{9} = 0.55556$	$\frac{25}{32} = 0.78125$
$\frac{3}{32} = 0.09375$	$\frac{1}{3} = 0.33333$	$\frac{9}{16} = 0.56250$	$\frac{13}{16} = 0.81250$
$\frac{1}{9} = 0.11111$	$\frac{11}{32} = 0.34375$	$\frac{7}{12} = 0.58333$	$\frac{5}{6} = 0.83333$
$\frac{1}{8} = 0.12500$	$\frac{3}{8} = 0.37500$	$\frac{19}{32} = 0.59375$	$\frac{27}{32} = 0.84375$
$\frac{5}{32} = 0.15625$	$\frac{13}{32} = 0.40625$	$\frac{5}{8} = 0.62500$	$\frac{7}{8} = 0.87500$
$\frac{1}{6} = 0.16667$	$\frac{5}{12} = 0.41667$	$\frac{21}{32} = 0.65625$	$\frac{29}{32} = 0.90625$
$\frac{3}{16} = 0.18750$	$\frac{7}{16} = 0.43750$	$\frac{2}{3} = 0.66667$	$\frac{11}{12} = 0.91667$
$\frac{7}{32} = 0.21875$	$\frac{4}{9} = 0.44444$	$\frac{11}{16} = 0.68750$	$\frac{15}{16} = 0.93750$
$\frac{2}{9} = 0.22222$	$\frac{15}{32} = 0.46875$	$\frac{23}{32} = 0.71875$	$\frac{31}{32} = 0.96875$

Units of length

Symbol

in	inch	= 0.0254 m
ft	foot (12 in)	= 0.3048 m
yd	yard (3 ft or 36 in)	= 0.9144 m

Symbol

—	statute mile (1760 yd)	=	1609.344 m
		=	1.6 km
μ or μm	micron or micrometre =		
	0.000001 m (10^{-6} m) =		0.000039 in
mm	millimetre	= 0.001 m =	0.039 in
cm	centimetre	= 0.01 m =	0.39 in
dm	decimetre	= 0.1 m =	3.9 in
m	metre	=	$\left\{ \begin{array}{l} 1.093 \text{ yd} \\ 39.37 \text{ in} \\ 3.281 \text{ ft} \\ 3 \text{ ft } 3 \frac{3}{8} \text{ in} \end{array} \right.$
km	kilometre	= 1000 m =	0.621 statute mile
		=	0.539 nautical mile

Units of area

in^2	square inch	=	6.4516 cm^2
ft^2	square foot (144 in^2)	=	0.0929 m^2
yd^2	square yard (9 ft^2)	=	0.83613 m^2
sq mile	square mile (640 acres)	=	2.5899 km^2
—	acre (4840 yd^2)	=	4046.8 m^2
cm^2	square centimetre = 0.0001 m^2 =		0.155 in^2
dm^2	square decimetre = 0.01 m^2 =		0.1076 ft^2
m^2	square metre or centare = 1 m^2 =		1.196 yd^2
hm^2 , ha	square hectometre or hectare		
	= 10 000 m^2 =		2.471 acres
km^2	square kilometre = 1 000 000 m^2 =		0.3861 sq miles

Units of mass and weight

—	grain	=	0.065 g
oz	ounce	=	28.349 g
lb	pound (16 oz)	=	453.592 g
—	stone (14 lb)	=	6.350 kg
—	quarter (2 stone)	=	12.70 kg
cwt	hundredweight (UK) (112 lb) . =		50.802 kg
sh cwt	short hundredweight (US)		
	(100 lb)	=	45.359 kg

Symbol

ton	long ton (UK) (2240 lb) . . . =	1.016 t
sh tn	short ton (US) (2000 lb) . . . =	0.907 t
mg	milligram = 0.001 g =	0.0154 grain
g	gram =	15.432 grain
kg	kilogram = 1 000 g =	35.2736 oz
		= 2.2046 lb
t	metric tonne . . = 1 000 000 g =	$\left\{ \begin{array}{l} 19.6841 \text{ cwt (UK)} \\ 22.0462 \text{ sh cwt} \\ 1.1023 \text{ sh ton} \\ 0.9842 \text{ ton (UK)} \end{array} \right.$

Units of volume and capacity

in ³	cubic inch =	16.387 cm ³
pt	pint (UK) (4 gills) =	0.5682 l
liq. pt.	liquid pint (US) (4 gills) . . . =	0.4732 l
qt	quart (UK) (2 pt) =	1.1364 l
liq. qt.	liquid quart (US) (2 liq. pt.) . . =	0.9464 l
gal (UK)	UK (Imperial) gallon (8 UK pt) =	4.54596 l
		= 1.2 gal (US)
gal (US)	US gallon (8 US liq. pt.) . . . =	3.78533 l
		= 0.833 gal (UK)
bu. (US)	US bushel (4 pecks) =	35.2383 l
ft ³	cubic foot =	28.3161 l
yd ³	cubic yard =	0.7645 m ³
cm ³	cubic centimetre ^a = 0.000001 m ³ } =	0.06102 in ³
	or	
ml	millilitre ^a . . . = 0.001 litre } =	
		0.220 gal (UK)
		0.264 gal (US)
l	litre = 0.001 m ³ =	0.03531 ft ³
		1.7597 pt (UK)
		2.113 liq. pt. (US)
m ³	cubic metre =	1.3079 yd ³

^a Metric units of length, and hence cubic centimetres for volume, are based on a temperature of 0°C, whereas units of capacity such as the litre and millilitre are based on a temperature of 4°C, the point at which water has its maximum density. Therefore 1 ml actually equals 1.000027 cm³. For practical purposes this distinction may be disregarded.

Units of rate of flow and of filtration

Symbol

ft ³ /s	cubic foot per second	= 28.315 l/s = 101.934 m ³ /h
gal/min (US)	US gallon per minute	= 227 l/h = 0.227 m ³ /h
		= 0.0625 l/s
gal/min (UK)	UK (Imperial) gallon per minute	= 272.758 l/h = 0.2727 m ³ /h
		= 0.07576 l/s
ft ³ /min	cubic foot per minute	= 0.4719 l/s = 1.6989 m ³ /h
l/s	litre per second	= 0.03531 ft ³ /s = 2.119 ft ³ /min
l/h	litre per hour	= 0.03531 ft ³ /h
m ³ /h	cubic metre per hour	= 0.589 ft ³ /min = 3.667 UK gal/min
m.g.d (UK)	million UK gallons per day . .	= 189.4 m ³ /h = 52.6 l/s
m.g.d (US)	million US gallons per day . .	= 157.7 m ³ /h = 43.8 l/s
gal/ft ² /min (US)	gallon per square foot per minute (US)	= 2.421 m ³ /m ² /h
gal/ft ² /min (UK)	gallon per square foot per minute (UK)	= 2.934 m ³ /m ² /h
ft ³ /ft ² /min	cubic foot per square foot per minute	= 18.29 m ³ /m ² /h = 0.340 UK gal/ft ² /min
m ³ /m ² /h	cubic metre per square metre per hour or	} { 0.413 US gal/ft ² /min 0.621 mile/h
m/h	linear speed of 1 metre per hour	} { 0.0546 ft ³ /ft ² /min

Units of pressure

lbf/in ²	pound-force per square inch	= 0.0703 kgf/cm ² = 0.068 atm
lbf/ft ²	pound-force per square foot	= 4.882 kgf/m ²
tonf/in ²	ton-force per square inch (UK) . .	= 1.575 kgf/mm ² = 157.5 kgf/cm ²
kgf/cm ²	kilogram-force per square centimetre	= 14.223 lbf/in ² = 0.9678 atm

Symbol

kgf/m ²	kilogram-force per square metre . . . =	0.2049 lbf/ft ²
atm	atmosphere =	1.033 kgf/cm ²
		= 14.696 lbf/in ²

Units of specific weight and concentration

lb/yd	pound per yard =	0.496055 kg/m
lb/ft	pound per foot =	1.48816 kg/m
lb/in ³	pound per cubic inch =	27.6799 g/cm ³
lb/ft ³	pound per cubic foot =	0.016019 kg/l
		= 16.085 kg/cm ³
grain/gal (UK)	grain per UK gallon =	14.2542 mg/l
grain/gal (US)	grain per US gallon =	17.1184 mg/l
lb/gal (UK)	pound per UK gallon =	99.7 g/l
lb/gal (US)	pound per US gallon =	119.0 g/l
grain/in ³	grain per cubic inch =	3.96 g/l
grain/ft ³	grain per cubic foot =	2.296 mg/l
kg/m	kilogram per metre =	0.672 lb/ft
		= 2.016 lb/yd
g/cm ³	gram per cubic centimetre . . . =	0.036127 lb/in ³
mg/l	milligram per litre =	0.0702 grain/gal(UK)
		= 0.0584 grain/gal(US)
		= 0.4356 grain/ft ³
		0.253 grain/in ³
g/l	gram per litre =	435.6 grains/ft
		70.2 grains/gal (UK)
		58.4 grains/gal (US)

Concentrations

1 per cent (%) × density of the solution . . . =	10 g/l
1 per thousand (1 ⁰ / ₁₀₀₀) × density of the solution =	1 g/l
1 part per million (p.p.m.) × density of the solution =	1 mg/l

Units of linear speed

in/s	inch per second =	91.444 m/h
ft/s	foot per second =	1.0972 km/h
yd/s	yard per second =	0.9144 m/s
mile/h	statute mile per hour =	1.6 km/h
m/s	metre per second =	3.281 ft/s
km/h	kilometre per hour =	0.621 statute mile/h

Units of energy and heat

Symbol

Btu	British thermal unit	=	0.252 kcal
		=	1.0548 kJ
Btu/ft ³	British thermal unit per cubic foot	=	8.899 kcal/m ³
kcal or kcal IT	kilocalorie or large calorie or I.T. kilocalorie (1000 small calories)	=	4.1868 kJ
kJ	kilojoule (1000 joules)	=	0.9478 Btu
		=	0.2388 kcal
th	thermie	=	3967 Btu
kcal/m ³	kilocalorie per cubic metre, or		
mth/m ³	millithermie per cubic metre	=	0.112 Btu/ft ³
kWh	kilowatt-hour	=	3412.14 Btu
		=	3600 kJ

Units of power

hp	horsepower (British)	=	0.7457 kW
		=	1.0139 ch
ft · lbf/s	1000 foot pound-force per second	=	1.35582 kW
Btu/s	British thermal unit per second	=	1.05418 kW
ch	cheval vapeur or metric horsepower	=	0.73575 kW
		=	0.9863 hp
kgf · m/s	kilogramme-force metre per second	=	0.0098 kW
		=	0.0132 hp
kW	kilowatt	=	1.341 hp
		=	1.36 ch

Equivalent values of metric, UK and US rates of flow

<i>Unit</i>	<i>m³/day</i>	<i>gal/min (US)</i>	<i>gal/min (UK)</i>	<i>m³/h</i>	<i>l/s</i>	<i>m.g.d. (US)</i>	<i>m.g.d. (UK)</i>
gal/min (US)	5.45	1	0.833	0.227	0.063		
gal/min (UK)	6.55	1.20	1	0.273	0.076		
m ³ /h	24	4.40	3.667	1	0.278		
l/s	86.40	15.85	13.198	3.600	1		
1000 m ³ /day	1 000	183.46	152.765	41.667	11.574		
m.g.d. (US)	3 785	694.44	579.72	157.726	43.811	1	
m.g.d. (UK)	4 546	834.06	694.445	189.415	52.615	1.200	1
m ³ /s	86 400	15 851	13 198	3 600	1 000	22.825	19.005

Temperature

(Centigrade and Fahrenheit)

<i>C</i>	<i>F</i>	<i>C</i>	<i>F</i>
0	32	40	104
5	41	50	122
10	50	60	140
20	68	70	158
30	86	80	176
37	98	90	194
(normal body temperature)		100	212
		(boiling point)	

To compute Fahrenheit: Multiply centigrade by 1.8 (or 9/5) and add 32.

To compute centigrade: Subtract 32 from Fahrenheit and divide by 1.8 (or multiply by 5/9).

Multiples and submultiples of metric units

Abbreviation	Prefix	Multiple or submultiple
M	mega-	× million
k	kilo-	× thousand
h	hecto-	× hundred
d	deci-	one-tenth
c	centi-	one-hundredth
m	milli-	one-thousandth
μ	micro-	one-millionth

Annex 4

CHEMICAL EQUATIONS

The chemical equations given in this monograph may be used to compute weight of chemical involved through the use of atomic and combining weights. This is because the proportion of atoms of any given element or compound which enters into a reaction is constant. Furthermore, the same proportions prevail whether expressed as atomic weights or in grams, pounds, milligrams per litre, or parts per million. In fact, atomic weights are not real weights, but relative weights based on the value of 16 for oxygen. For example, water, H_2O , consists of 2 atoms of hydrogen and one atom of oxygen. The atomic weight of hydrogen is 1, that of oxygen is 16. Then $\text{H}_2 = 2 \times 1$ and $\text{O} = 16$, so $\text{H}_2\text{O} = 18$. This means that in 18 g water there are 2 g hydrogen and 16 g oxygen.

As stated in Chapter 5, compounds which separate into positive and negative portions when dissolved in water are called *electrolytes*, and the process is called *ionization*, each electrically charged portion being an *ion*. The positive ions are called *cations*, and the negative ions, *anions*. Cations will not react with one another, nor will anions react with other anions, because they have like electrical charges. Furthermore, when a cation reacts with an anion, their charges must be opposite and equal. Hence ferric chloride ionizes thus: $\text{Fe}^{+++} + 3\text{Cl}^-$; three chloride ions with a single negative charge each are required to balance the three positive charges of the ferric ion. Contrast this with sodium chloride, Na^+Cl^- , where only two single opposite charges are involved.

Many compounds have negative ions that consist of more than one element. For instance, sulfuric acid, $\text{H}_2^{++}\text{SO}_4^{--}$, consists of two positive hydrogen ions and one negative group, SO_4^{--} , having two negative charges. Such groups of atoms, when ionized as a group, are called *radicals*.

Ions, then, combine with ions of opposite charge in definite proportions, depending on their electric charge. This charge, in controlling the reacting ratios of ions, is called *valence*. Thus chlorine, Cl^- , has a valence of 1, Ca^{++} and SO_4^{--} have valences of 2, and aluminium, Al^{+++} , has a valence of 3. Since an atom or radical having a valence of, say, 2 will combine with two atoms or radicals having a valence of 1, the *combining weight* of any given atom is its atomic weight divided by its valence. For example, chlorine has an atomic weight of 35.46 and a valence of 1, so its combining

weight is 35.46; but oxygen, having an atomic weight of 16.0 and a valence of 2, has a combining weight of 8.0.

Oxidation and reduction

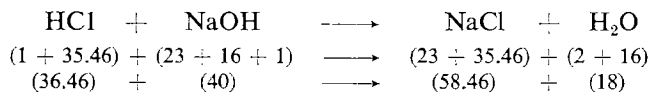
Certain elements have more than one valence, so the magnitude of reaction with such elements is measured by the increase or decrease in valence that occurs in a specific reaction. For instance, carbon, C, has valences of 2 and 4. When carbon is oxidized to carbon dioxide, CO_2 , 4 valence units are involved; when it is oxidized to carbon monoxide, CO , only 2 valence units are involved. If, however, carbon monoxide is oxidized to carbon dioxide, 2 valence units are involved. The amount of oxygen entering into these reactions is dependent on the change in valence of the carbon, but the amount of carbon involved does not change.

Because reactions involving an increase in the valence of those elements with more than one valence frequently involve oxygen, the term *oxidation* is used broadly to denote those reactions in which the valence is increased. For instance, ferrous chloride is said to be oxidized by chlorine to ferric chloride ($\text{FeCl}_2 + \text{Cl} = \text{FeCl}_3$) even though no oxygen is involved, because the valence of the iron is increased from 2 to 3. Conversely, the term *reduction* is used when oxygen is removed or when a valence is reduced. Thus when insoluble ferric oxide is reduced to ferrous oxide ($2\text{Fe}_2\text{O}_3 = 4\text{FeO} + \text{O}_2$), the valence of iron is reduced from 3 to 2. Incidentally, the ferrous oxide in turn is dissolved by waters containing carbon dioxide (carbonic acid) to form the soluble ferrous bicarbonate: $\text{FeO} + 2\text{H}_2\text{CO}_3 = \text{FeH}_2(\text{CO}_3)_2 + \text{H}_2\text{O}$. These are the reactions which occur when ground waters devoid of oxygen but containing carbon dioxide come in contact with iron-bearing rocks.

Combining weights

Table 26 gives the basic data as to these properties of the common atoms and radicals encountered in water treatment.

The use of Table 26 may be illustrated by the neutralization of hydrochloric acid by sodium hydroxide.



It will be noted that the weight of compounds formed equals the weight of the reacting substances, so no loss occurs. Therefore 36.46 parts hydrochloric acid by weight reacts with 40 parts sodium hydroxide to form 58.46 parts neutral sodium chloride, or salt, and 18 parts water; so 36.46 g of this acid would combine with 40 g sodium hydroxide to form 58.46 g sodium chloride and 18 g water.

TABLE 26
 ATOMIC WEIGHTS, VALENCES AND COMBINING WEIGHTS OF ELEMENTS
 AND RADICALS INVOLVED IN WATER TREATMENT
 (Only the most common valences shown)

Element or radical	Atomic symbol	Atomic weight	Valence	Combining weight
<i>Elements :</i>				
Aluminium	Al	26.98	+ 3	8.99
Calcium	Ca	40.08	+ 2	20.04
Carbon	C	12.01	+ 4	3.00
Chlorine	Cl	35.46	- 1	35.46
Copper	Cu	63.54	+ 2	31.77
Hydrogen	H	1.008	+ 1	1.008
Iodine	I	126.91	- 1	126.91
Iron	Fe	55.85	+ 3	18.62
Magnesium	Mg	24.32	+ 2	12.16
Manganese	Mn	54.93	Several	
Nitrogen	N	14.01	Several	
Oxygen	O	16.00	- 2	8.00
Potassium	K	39.10	+ 1	39.10
Sodium	Na	23.00	+ 1	23.00
Sulfur	S	32.06	Several	
<i>Radicals :</i>				
Bicarbonate	(HCO ₃)		- 1	61.01
Carbonate	(CO ₃)		- 2	30.00
Hydroxyl	(OH)		- 1	17.00
Nitrate	(NO ₃)		- 1	62.01
Nitrite	(NO ₂)		- 1	46.01
Phosphate	(PO ₄)		- 3	31.66
Silicate	(SiO ₃)		- 2	38.05
Sulfate	(SO ₄)		- 2	48.03

If, however, sulfuric acid, for example, is involved, the equation is:



It will be noted here that the sulfate radical or ion, having a valence of 2, combines with two sodium atoms having a valence of 1. This means that twice as much sodium hydroxide must be used to neutralize each molecule of sulfuric acid, as compared with hydrochloric acid. As it is

desirable to use a valence of 1 as the unit for comparison, the above formula is computed as follows:

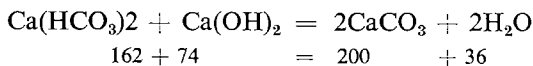


In other words the combining weight of sulfuric acid is its molecular weight divided by the valence of 2 of the sulfate radical, SO_4 , or

$$\frac{2 + 32.06 + 64}{2} = \frac{98.06}{2} = 49.03$$

That is, 49.03 parts sulfuric acid will neutralize 40 parts sodium hydroxide.

In the same way, the weights of chemicals used in water treatment may be computed. For example, the precipitation of calcium bicarbonate, or carbonate hardness, by hydrated lime is as follows:



Therefore 74 parts pure calcium hydroxide are required to precipitate 162 parts calcium bicarbonate. The same ratio may be expressed in terms of combining weights: $74/2 = 37$, and $162/2 = 81$, or 37 to 81.

The general procedure is to use the ratio of combining weights of chemicals in computing the quantities of reacting substances. As an example, the combining weight of calcium bicarbonate, 81, is equivalent to the value of 50 for calcium carbonate. Since hardness and alkalinities are in terms of calcium carbonate, the above ratio becomes: 37 parts pure calcium hydroxide to 50 parts alkalinity.

The combining weights may be expressed in terms of grams, pounds, milligrams per litre, or parts per million. For instance, 37 p.p.m. pure calcium hydroxide will precipitate 81 p.p.m. calcium bicarbonate, expressed as 50 p.p.m. hardness or alkalinity computed as calcium carbonate.

The ratio of combining weight to weight of reacting chemicals may be expressed as follows:

$$\begin{array}{l} \text{Combining weight} \\ \text{of substance } a \end{array} : \begin{array}{l} \text{combining weight} \\ \text{of substance } b \end{array} :: x : 100$$

$$\text{Then} \quad x = \frac{a}{b}$$

The factor x may be recorded and used thereafter for the specific reacting substance in the *pure state*. For example, the reaction between calcium hydroxide and calcium hardness would be computed as follows:

$$x = \frac{37}{50} = 0.74$$

Therefore the dose of pure calcium hydroxide needed to precipitate, say,

TABLE 27
 MOLECULAR WEIGHTS AND COMBINING WEIGHTS OF PRINCIPAL COMPOUNDS
 INVOLVED IN WATER TREATMENT

Substance	Formula	Molecular weight	Combining weight
Aluminium hydroxide	$\text{Al}(\text{OH})_3$	78	26
Aluminium sulfate	$\text{Al}_2(\text{SO}_4)_3$	342	57
Calcium bicarbonate	$\text{Ca}(\text{HCO}_3)_2$	162	81
Calcium carbonate	CaCO_3	100	50
Calcium hydroxide	$\text{Ca}(\text{OH})_2$	74	37
Calcium oxide	CaO	56	28
Calcium sulfate	CaSO_4	136	68
Ferric chloride	FeCl_3	162.5	54.2
Ferric hydroxide	$\text{Fe}(\text{OH})_3$	106.84	35.61
Ferric oxide	Fe_2O_3	159.70	26.61
Ferric sulfate	$\text{Fe}_2(\text{SO}_4)_3$	400	66.6
Ferrous oxide	FeO	71.84	35.92
Ferrous sulfate	FeSO_4	152	76
Hydrochloric acid	HCl	36.5	36.5
Magnesium bicarbonate	$\text{Mg}(\text{HCO}_3)_2$	146	73
Magnesium carbonate	MgCO_3	84	42
Magnesium hydroxide	$\text{Mg}(\text{OH})_2$	58	29
Magnesium sulfate	MgSO_4	120	60
Sodium bicarbonate	NaHCO_3	84	84
Sodium carbonate	Na_2CO_3	106	53
Sodium chloride	NaCl	58.5	58.5
Sodium hydroxide	NaOH	40	40
Sodium silicate	Na_2SiO_3	122	61
Sodium sulfate	Na_2SO_4	142	71
Sulfuric acid	H_2SO_4	98	49

185 p.p.m. calcium hardness would be 185×0.74 , or 137 p.p.m. The dose of 95% hydrated lime required would be $137/0.95$, or 144 p.p.m.

Combining weights are shown in Table 27 for the principal compounds involved in water treatment.

Standard solutions

The use of the combining weights of atoms or radicals in the laboratory is made convenient by the preparation of standard, or normal, solutions of

the various reagents. Such a solution is prepared by adding to 1 litre of distilled water the weight in grams of the substance equal to its combining weight. This is called the *gram-equivalent weight*, because it is equivalent in chemical activity to 1 g hydrogen in 1 litre, the latter having the unit value of 1.

$$\text{Gram-equivalent weight} = \frac{\text{molecular weight}}{\text{valence}}$$

A standard solution of sulfuric acid, for example, would be prepared by adding its gram-equivalent weight ($98/2 = 49$ g) to 1 litre distilled water. This is normal, or N, H_2SO_4 solution. The standard solutions used in the analysis of water are usually diluted to $1/50$ their normal strength, so as to secure greater accuracy. These diluted solutions are expressed as N/50 or 0.02N.

Since all gram-equivalent weights of reacting substances have the equivalent values, it is possible to measure the unknown concentration of a reacting substance by the known amount of another substance with which it reacts. Thus the unknown alkalinity of a water sample is measured by adding 0.002N H_2SO_4 to the point where the alkalinity is neutralized by the acid, as shown by the methyl orange indicator. As the 0.02N acid solution has a definite weight of acid per unit of volume, measuring the volume with a burette means that a weight is being measured: each millilitre of 0.02N sulfuric acid will neutralize 1 mg calcium carbonate. Since 1 mg per litre is the same as 1 p.p.m., and 1 mg per 100 ml is equal to 10 p.p.m., 1 ml of 0.02N sulfuric acid will neutralize 10 p.p.m. alkalinity in a 100-ml portion of a sample. Thus the alkalinity of a sample is computed by multiplying by 10 the amount of 0.02N acid used when 100 ml of the sample is titrated. This is the origin of the factor of 10 mentioned in that portion of the Supplement dealing with the test for alkalinity.
