TASTE AND ODOR CONTROL IN DOMESTIC WATER SUPPLIES

Dissertation Submitted In Partial Fulfilment Of
The Requirements For The Degree Of

MASTER OF ENGINEERING

(Public Health Engineering)

by

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University Of Roorkee
Roorkee

CERTIFICATE

CERTIFIED that the dissertation entitled TASTE AND ODOR CONTROL IN DOMESTIC WATER SUPPLIES. which is being submitted by Sri Manmohan Nath Bhatla in partial fulfilment for the award of the Degree of Master of Engineering in Public Health Engineering. (Civil Engineering). of University of Roorkee is a record of student's own work carried out by him under my/our supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of Four and half months from 15th April to 31st August. for preparing dissertation for Master of Engineering Degree at the University.

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The author does not claim anything new or original but has only systematically represented the information after studying the literature available on the subject. All the sources of information are duly acknowledged in the bibliography given in the end.

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Dated:

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ABSTRACT

The author has tried to review the studies that have been made in taste and odor problems. This text deals with the causes of taste and odor, their detection and measurement and their control in domestic water supplies.

As U.S.A. is poineer in the field of Sanitary Engineering, therefore, most of the references made in this study are from the experiences gained in that country. The problem of taste and odor has not so far been tackled in India as per the report from Central Public Health Research Institute of India.

The different aspects of problem are discussed in the following pages.

1. INTRODUCTION

1.1. Development

Primitive man just wanted to quench his thirst and like animals did not care much for quality of water i.e. whether it was clean, safe and palatable. He was ignorant of the implications of contaminated water. For him water was a God sent gift. It was only in nineteenth century that water was indicated to be a carrier of diseases. Water was drunk as a necessity for the health and was not considered a luxary.

As the civilisation advanced, man left jungles and caves, started building houses and living in groups; he, also, developed keener power of observation and finer senses to appreciate things. He could no longer tolerate a water excessively odorous or giving bad taste. But, only alternative he had was to abandon such water sources in favour of more palatable ones. Clean and sparkling water without excessive taste and odors came to be criterion of good water. No attempts were made to remove taste and odor, because of lack of technological advancement in water purification field. Also, most of people got accustomed to certain more commonly met tastes and odor in water.

History of water purification reveals that both animal and vegetable charcoal was used as filtering media in the beginning of 19th Century to get palatable water for domestic use. Water was made to trickle through earthenware pitchers one above the other containing charcoal and the water collected from bottom most pitcher used for consumption. It is definite that potentialities of charcoal as remover of odor and taste were not comprehended and its use was merely as a filtering media to free water from turbidity. But people knew that charcoal could make water more palatable than sand filtering media. Now we fully understand the utility of charcoal as a deodorant and attempts to increase the efficiency of Charcoal to remove odor has resulted in use of powdered activated carbon a modern odor treatment method.

Now that the civilisation has taken many a turns, people bothering for safety of water, which itself is not an old idea (as no body knew that diseases can be disseminated by ingestion of water up till later half of 19th century), started craving for palatability of water also. The developed aesthetics of man came to amend the processes of water purification to have a water free from taste and odor. Positive efforts to achieve palatable water started in the beginning of 20th century in U.S.A. and much has been studied about various aspects of taste and odor problem; chemical, biological, psychological and physiological. Taste and odor control measures both preventive and corrective are becoming part of the water works plant having this problem. In U.S.A., some plants are spending two times the amount what they spend on disinfecting chemicals, being used in plant, to get a palatable water. Still a lot remain to be explored and awaits future probe in this matter.

Recently a taste and odor research project has started at the Franklin Institute, Philadelphia, U.S.A., Franklin Institute will attempt to pin down some of the subjective aspects of taste and odor. Its main aim being to find a reproducible method for measuring the intensity of an odor. The researchers, there, will also attempt to creat a system for characterizing ------- or labelling ------- odors, so that all scientists working in the field will have some common terms of reference.

1.2. Importance of Palatability.

The desirability of supplying a palatable water to the public has long been realised. In the history of water purification itself, it is clearly indicated that long before safety of water supplies was considered, there was a persistant endeavor to find some means of making them more attractive in taste, odor and appearance. And when modern water utilities came into existence, the responsible-officials soon became aware of the importance of palatability as a means of keeping their customers satisfied.

Flavour in the foods people eat and drink is determined by a combination of their sense of taste and smell and the food industry is heeding public demand for products with most satisfying flavor. Consumers naturally prefer foods and beverages which are most pleasing to senses of sight, taste and smell. In advanced countries like U.S.A., for reasons of high aesthetic sense a housewife would purchase a specific brand of soap merely because it, or its wrapper happens to blend in the color scheme of the bathroom, no matter if it costs her more. Certainly with such an attitude, the public cannot logically object to minor increase in costs which will assure the deli-

delivery of a consistently palatable water. Aesthetic appeal of water is essential apart from safety. An unpalatable water could constitute to health menace if consumers were so dissatisfied that they would obtain drinking water from local springs or wells which though more palatable may serve as foeii of disease dissemination. Illustrative of the effert exerted to achieve palatability have been the recent major research and development in the field of water disinfection, a great deal of water is directly traceable to the tendency of chlorine to aggravate certain taste and odor conditions in the process of making water safe.

The practice of flouridation of water supplies to aid in the reduction of dental caries has been adopted in a large number of Communities throughout the United States. Effectiveness of the treatment depends upon a consistent and relatively uniform ingestion of the fluoridated water. Therefore, water palatability assumes major importance if the desired beneficial results are to be assured.

Except for air, water is most vital requirement for human existence. Some members of medical profession in United States have (1) advised that a normal individual should have water intake of 2 qt/ day. Complying with such advice would constitute no problem where a constantly palatable water was available. Of course, no body will stop taking water if no source is available other than the one supplied but still it will cause deficiency of water in people for want of palatability.

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2. MODERN TRENDS

Older concepts of quality requirements for finished water appear to be shaped by several trends. First as the standard of living rises and "luxary" market expands, there is a continuing pressure for highest possible quality of water, uptill now modern American demand is the finest. Water having tastes and odors can never be tolerated by the users. Not to speak of taste and odor, water supply is used to supplement our food diets as floridation,iodine etc, through domestic water supply. Finally, concepts of finished water are being shaped by improved methods of analysis. Where as all the water chemists relied on simple physical and chemical tests, he now has at his disposal equipment like flame photometer or, perhaps, even the infra red spectrophotometer to measure trace elements and adsorptive devices such as carbon filter for Micro-analysis of odoriferous compounds, liquid and gas-chromatographic procedures and several other recent improvements. While many of the above techniques are applied in research laboratories for detection of taste and odor. Their impact will be felt in water- works practice in course of time.

Forecasts are being made by American water works Association and other in United States that an appreciable demand of water will be experienced in the near future; such demands will be augmented by an expanded usage of water by industry and Agriculture alike. Underground supplies are already taxed to limit of capacity, so any further demand would naturally be tapped from surface water which can be expected to carry great loads from our mounting industrial expansion. It can be anticipated that odor problems will be intensified even though industrials are cognizant of the situation and are making every effort to reduce the wastes. Domestic wastes have not constituted a serious problem in past year, but some sanitary engineers are now viewing these wastes with alarm in view of the continuing upsurge in the use of synthetic detergents. Foam and odor problems are only a part of their concern. Phosphates which are incorporated as builder in synthetic detergents, are one of the foods on which algae can thrive, thus further complicating odor problems. Modern roads, particularly those which are oiled or tarred, can also contribute taste and odor producing substances to surface supplies; and of course,the very availability of these roads has made possible greater access to, and thus pollution of public water sheds. There are indications, too, that the spread of aviation can be expected to add still more to the problems of water purification. Taste and odor difficulties have, for instance, occured at Chicopee, Mass., where a landing field was constructed on water-shed. Transport planes returning from abroad were forced to jettisan surplus fuel, and frequently this gasoline found its way into Chicopee water supply. Leakage from such long-line systems as the 'Big Inch' oil line is still another example of how modern transportation constitutes a threat of further contamination of water supplies (2)-.

Added public demand for palatable water as well had resulted in greater attention to the correction of tastes and odors. In India not much is done in this subject while in United States many plants are now delivering palatable water to their consumers, too much remains to be done. Abel Wolman (6) in his report on 75 years of water quality Improvement Stated " The road to universally palatable water, however, has been only partially traversed, even though suitable control methods are available. " Some operators refuse to admit their responsibility to consumers, while other laugh off complaints and still other donot know that the water they are delivering is unpalatable. John Baylis statement in 1924 is still appreciable in many communities to-day and is worthy of reception " The removal or prevention of objectionable taste should receive more consideration from our water-works officials. "

There are many progressive water works officials throughout the United States, however, who are showing an increasing willingness to spend whatever is necessary to reduce taste and odor to palatable levels. During 1956(7) the city of Chicago expended nearly $ 150,000 for activated carbon to control tastes and odors at the South District filteration plant. This expenditure represented about 25% of the entire chemical costs where as the cost of chlorine for disinfection was only 16% of total chemical costs. Thus this plant is spending more money to accomplish water palatability than is necessary to make the water safe for human consumption. The reposible officials are proved of the accomplishment that they have adopted the Slogan "Every drop Pure and Palatable."

Ralph Porges (8) reported that 202 plants, out of a total of 570 upto January 1955 in communities of 25000 populations or over, were employing corrective treatments for tastes and odor controls in U.S.A.

3.- PHYSIOLOGY

The words taste and odor are generally used loosely and, to a certain extent, interchangeably. Much of sensitivity customarily attributed to gustation (taste) is actually due to odor of the stimulus. When olfactory reception is eliminated, recognition of many common substances is diminished or even eliminated. One may recall how 'flat' may things taste when one has a cold in head. Actually there are but four tastes, sour, salt, sweet and bitter (fig 1.) which are strictly confined in the perception to the taste buds of tongue. These taste buds occur in clusters in the papillae of the tongue and a few are scattered on the soft palate, epiglottis and pharynse. In the tip of each taste bud there is a minute pore through which substance in solution can enter and stimulate the receptor cells. Only substances in solution can exite the sense of taste hence one of the functions of the saliva is to dissolve dry substances so that they can be tasted. Hence only soluble substances can be tasted. Taste sensations depends upon nervous impulses excited by a chemical change. Same effect can be achieved by mechanically tapping the tounge or by passing continuous electrical current. The time required to excite taste after sapid substance was placed on tongue varies from

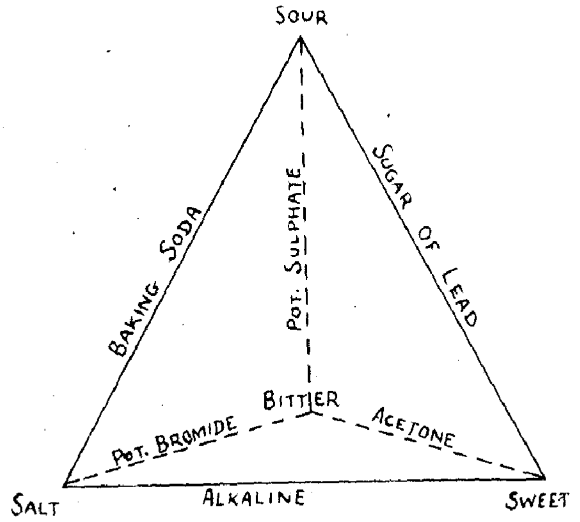

Fig.1.

Fig.1.
Henning's taste tetrahydron (after Henning, Der Geruch, 1916) representing the four taste qualities, which are said to grade off into each other, the figure is hollow & all tastes can be represented upon the suface.

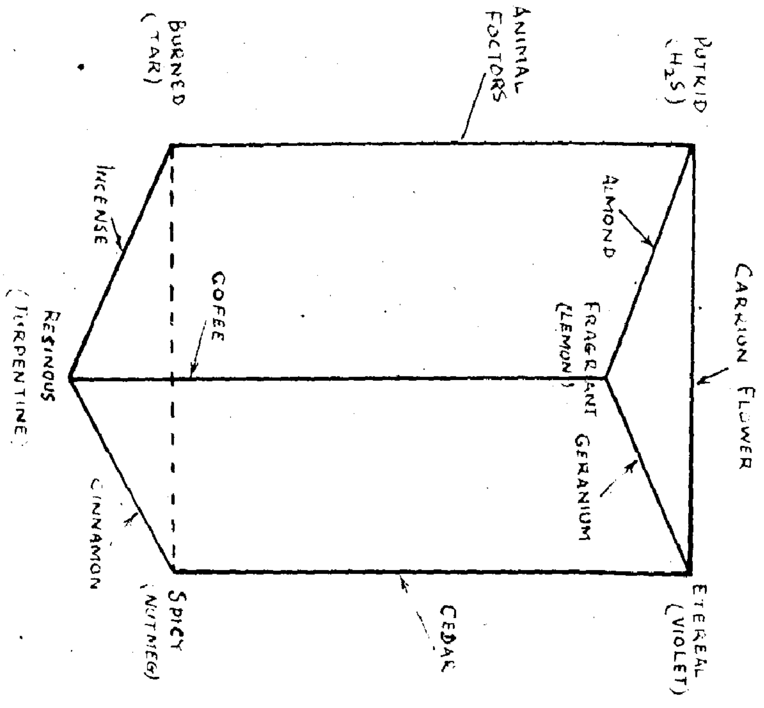

Fig.2.

Fig. 2.
Henning's odor prism (after Henning, Der Geruch 1916) representing the different olfactory qualities, which are said to grade off into each other. The prism is hollow, & all odor qualities can be represented upon the surface of prism.

From. General Psychology by J.P. Gmlford.

.17 secs. for saline taste to .258 secs. for bitter taste, with time for sweet and sour taste occuring in between in that order. Corresponding to color-blind individuals as regards vision, there are persons who lack taste sensitivity to certain substances, although they may possess all primaries otherwise. This immunity against certain tastes is more common in men and is hereditary. For example one substance known as Phenyl-thio-carbanide is tasteless to about 25% of white population, where as it tastes bitter to most of people, sour to a small percentage and even salty or sweet to few.

Odors appear to be unlimited in number, and they are known to change quality as the concentration of odorous compounds or the intensity of their smell is varied. However, careful screening of odors has identified certain fundamental odors from which all odors can be compounded. The best known classification is that of Henning (1916). He lists six primary odors: (1) fragrant, (2) fruity, (3) spicy, (4) putrid, (5) resinous and (6) burned (fig. 2). Odors are sensed through the olfactory area which is stituated high in human nose. Minute cilia, or hairlike receptors, extend from the cell that cover the olfactory nerve fibers. Perception of odors is commonly assumed to require the adsorption of the molecules of odorous substances by the watery and oily covering of olfactory, area; but other mechanisms of olfaction have also been suggested. As in other sensitivities, continued exposure to stimulation results in adaptation. In olfactory, the rate of adaptation is more rapid than in any other sense department. Hence sudden exposure to odor is recommended for determining threshold odors accurately. Stimulation of the olfactory sense organ by more than one odor may result in masking of an odor by another, resulting in odor threshold below perceptible limits. Intensification of fused odor is also likely . Based on the above observation, use of odor-masking or deodorant compounds for supressing undesirable traces of odors in water is a possibility.

A new technique is now being used in the United States in an effort to determine how the senses of tastes and smell function (61). This involves recording electrical responses of the taste cells, as well as the olfactory, by trapping into the specific nerve fibers. With the delicate instruments now available, it is possible to "listen in" on the messages as they are being carried to the brain.

From the experimental data obtained from many different kinds of animals which were subjected to many tastes a theory has been developed on how people tastes. This theory involve adsorption and ion exchange principles and an equation has been developed to cover various tastes and responses. These studies confirm the previous theory that there are only four tastes sensations and that all other so-called tastes are actually odors.

Studies on the olfactory responses have just recently resulted in development of methods of quantitative measurements, but a satisfactory theory has yet to be developed. Tests show that trigminal nerve fibers donot enter the mucous layer covering the olfactory epithelium. Since no specialized structures are known to exist at the nerve endings, just how they are stimulated by odors remain a mystry.

Such extensive studies would probably have greater significance for food and beverages, where flavor is an essential factor. In their proper enviornment an individual can enjoy the aroma of fish, cucumber, geranium, and even newly mown hay; yet he would be highly critical of a potable water containing any of these odors.

The public expects water to be free from detectable taste or odor when it is used for cooking, bathing or drinking purposes. Thus, complete removal is not necessary, but taste or odor producing substances must be rendered to concentration which are below detectable levels. Based on the fact that there are only 4 (four) taste sensations, it will be seen that predominant problems of water/palatability are those of odors rather than tastes.

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4. DETECTION AND MEASUREMENT OF ODORS

There are several kinds of sensations to which the term "taste" or "odor" are loosely applied. First, as already said, there are four true tastes (Art 3.). These correspond to localized sensitive areas on the tongue. Second, there are irritating sensations; the "hotness" of chill, the coldness of mint, the astringency of alum, the irritation of corrosive gases. These are responses of mucous memberances. Finally there are true odors, sensations which are experienced only when the odoriferous matter comes in contact with the olfactory tissue high up in the nose. If one tastes a sample with the nose tightly closed, odor cannot be perceived, but taste and the irritating sensations are still perceived. All of these sensations are subjective; there is no way to describe a taste or an odor without reference to the experience of a human being in the way that we can measure or describe heat, light or sound in terms of physics. Therefore, all descriptions of tastes or odors must be in terms of comparisions with tastes or odors with which it must be assumed the reader is familiar.

4.1.

4.1. Application and Scope

Odors in water may be associated with the presence in the sample of pollution or other objectionable matter, such as decomposing organic matter, planktons or industrial wastes. Determination of odor quality and intensity will assist in indicating the likelihood of consumer complaints and in helping to prevent or correct undesirable conditions. The determination may facilitate the search for plankton organisms and may point out the need for special tests such as those for sulphides, phenol, or chlorine. Heating a sample usually intensifies its odor, and a procedure is presented for "hot odor" as well as one for "Cold Odor". Compounds which cause tastes and odors in water supplies are so varied and are present in such small concentrations that they usually defy analysis by conventional analysis (27), although recently some of these odoriferous substances (specially organic substances) have been concentrated and isolated (28,29). Chloroform - soluble carbon filter extract (CSCFE) is one of the methods practiced to estimate organics in polluted water. Other equipment like flame photometer, even the infrared spectrophotometer are used to measure the traces of elements causing odors.

4.2. MEASUREMENT OF ODOR

Principle: The olfactory sense is a most sensitive means for detecting small concentrations of odoriferous substances, but, unfortunately, it lacks precision. There is no absolute odor value. Different persons react differently to a given odor concentration of odoriferous substance at different times. Therefore, it follows that an odor value obtained on a certain day should not be compared with a value obtained on another day unless there is some common basis for comparision. There are 2 ways of making odor values more precise, and both are recommended. The first is to compare the unknowns continually with a freshly prepared solution of a known concentration of an odorous substance such as phenol or butyl alcohol. The second is to average the results of as many observers as possible; for instance; as many as 15 persons panel is used in evaluating the flavour of food in commercial testing laboratories.

Selection of Procedure: Two procedures for determining odor are given. The method to be used depends upon the purpose for which the test is intended. The first ODOR QUALITY, best suited for the interpretation of consumer complaints and for assistance in deciding when odors caused by microscopic organisms are excessive; the second, THRESHOLD ODOR, is best suited for use in treatment plants in determining the odor removal treatment required, or for water systems in which variable proportions of two or more separate supplies may be mixed.

In U.S.A., of 241 plants reporting an odor evaluations approximately 82% run odor tests and most of these run odor tests daily and more frequently. Approximately 31% of the reporting plants utilize 1st method & 42% of the plants utilize 2nd technique.

The only practical method available to the water works profession for measurement of odor concentration is the "Threshold odor Test", in which the odor is measured by an operator smelling samples of the odorous water after these samples have been diluted in various proportions with odor free water. Thus utilizing the same means for evaluating odors that the consumer uses as a basis for complaints about palatability. The plant operator, however, takes advantage of every available refinement for his observation. As the sensitivity of individuals to odors is variable, the observer must of course

Figure. 3.

Odor Test in Making.

correlate his results with consumer reaction.

The "Threshold odor test" was devised by Charles Spaulding at Springfield, Illinios, in 1931 (3) and the procedure has been modified and improved to the extent that it gives results which enable the plant operator to improve the palatability of water delivered to consumer (30-37). Essentially, the test consists in comparing various dilutions of an odorous sample (diluted with odor-free water) with an odor free standard. The THRESHOLD POINT is reached when the odor of the diluted odorous water is last detected on increasing dilutions, this point being expressed quantitatively by the THRESHOLD ODOR NUMBER, which is simply the number of times the odor bearing water is diluted with odor-free water. If, for example the threshold point of a water sample is reached when 25 ml. of the sample is diluted to 250 ml. with sodor free water, the threshold number of the sample would be 10, obtained by dividing 250 by 25. The fundamental principles of this test have been maintained, but with refinements instituted.

Samples should be taken as often as experience indicates that a change is likely to occur in the raw water. It is also possible to make this interval

Agree with the length of time that it takes for the water to travel through the sedimentation basins. As an average figure we, therefore recommend that samples be drawn regularly every four hours from the following points for testing (1) raw water; (2) settled water; (3) filtered water; (4) tap water.

The sampling bottles used for this purpose should be of the wide-mouthed type, with ground glass stoppers. They should be carefully cleaned and rinsed with odor free water immediately before sampling. It is important that the sample be taken at such a place that it will be truly representative of the quality of water it is supposed to represent. For example, in taking the settled water sample, care should be taken to obtain a sample in exactly the same condition as it will be when it flows upon the filters. Sampling at points where eddy currents effect the flow should be avoided. The bottle should be completely filled. Samples are not taken from a tap until sufficient water was been wasted to empty the local line of water that was in it. After collecting the samples keep them in a cool place away from light before testing, just as is done in collecting samples for bacterial tests. Allow the floc to settle out of the settled water sample throughly before testing.

4.3. Procedure

4.3.1. Precautions.

Certain conditions are required to obtain consistent results. The analyst should avoid smoking or consumption of highly seasoned food prior to testing. The odor-free water, when prepared, should be truly free of all detectable odor. All glassware must be odorfree. All dilutions when examined for odor should be at the same temperature (with in 1° C). Each dilution should be compared with an odorless standard. To eliminate psychological influences, the samples should be coded by another person before they are given to another analyst, and dilutions should be examined in such a manner that the analyst does not know in advance what odor concentration is being observed. The test should be conducted in odorfree room. Test should not be prolonged to a point at which fatigue sets in; the testing period should be interrupted by frequent rest periods. In samples characterised by a strong odor., it is desirable to begin with dilutions below the detectable threshold.

4.3.2. Cold Odor Quality.

Shake about 250 ml. sample at 20°C in a 500ml.

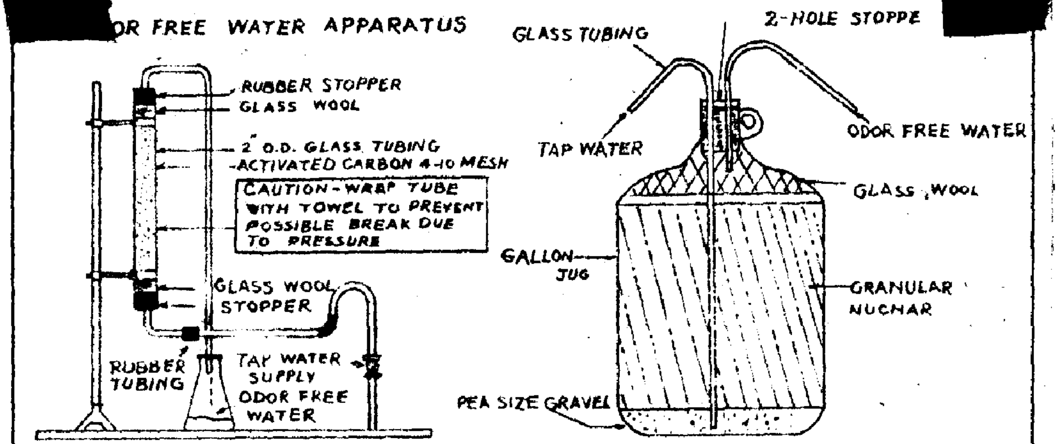


FIG. 4 a.

FIG. 4 b.

GRANULAR NUCHAR FOR ODOR-FREE GENERATOR

wide-mouth Erlenmeyer flask. Lightly sniff the odor. Use of glass nosepiece is optional for operation. Avoid vigorous or repeated shaking as the odor will be dissipate

4.3.3. Hot Odor Quality

Pour about 250 ml. sample into a 500 ml. Erlenmeye flask. Close the mouth of flask with a watch glass. Heat the water to approximately 58° to 60°C: agitate it with a rotary movement; slip the watch glass aside; and sniff the odor.

4.3.4. Expression of Results.

The odor is reported as to both intensity and type

Intensity.	Defination.
0	No Odor detectable.
I	Odor would not be detectable by an experienced observer.
II	Odor might be detected by an average consumer but only if his attention were called to it.
III	Odor would be readily detected and might cause the water to be disregarded with disfavor.
IV	Odor would force itself upon the attention and might make the water unpalatable.
V	Odor ef such intensity that the water is absolutely unfit to drink (used only in extreme cases).

4.3.5. Odor Type.

Abbreviation.		Nature of Odor	Description - such as odors of
A		Aromatic (Spicy)	Camphor, Cloves, Lavender, Lemon.
	Ac	Cucumber	Synura
B		Balsamic(flowery)	Geramium, Violet, Vanilla.
	Bg	Geramium	Asterionella
	Bn	Nasturtium	Aphanizomenon
	Bs	Sweetish	Coelosphaerium
	Bv	Violets.	Mallomonas.
C		Chemical	Industrial wastes or Chemical treatment.
	Cc	Cholorinous	Free chlorine.
	Ch	Hydrocarbon	Oil refinery wastes.
	Cm	Medicinal	Phenol and Iodoform
	Cs	Sulfuretted	Hydrogen Sulphide
D		Disaggeeable	(Pronounced unpleasant odors)
	Df	Fishy	Uroglenopsis and Dinobryon.
	Dp	Pigpen	Anabaena
	Ds	Septic	Staleo Sewage.
E		Earthy	Damp earth.
	Ep	Peaty	Peat
G		Grassy	Crushed Grass.
M		Musty	Decomposing straw
	Ms	Moldy	A damp cellar
V		Vegetable	Root vegetables.

Results are reported on both hot and cold samples. The intensity and type are recorded in the form 'VDp', which would represent a water unfit to drink due to excessive Anabaena.

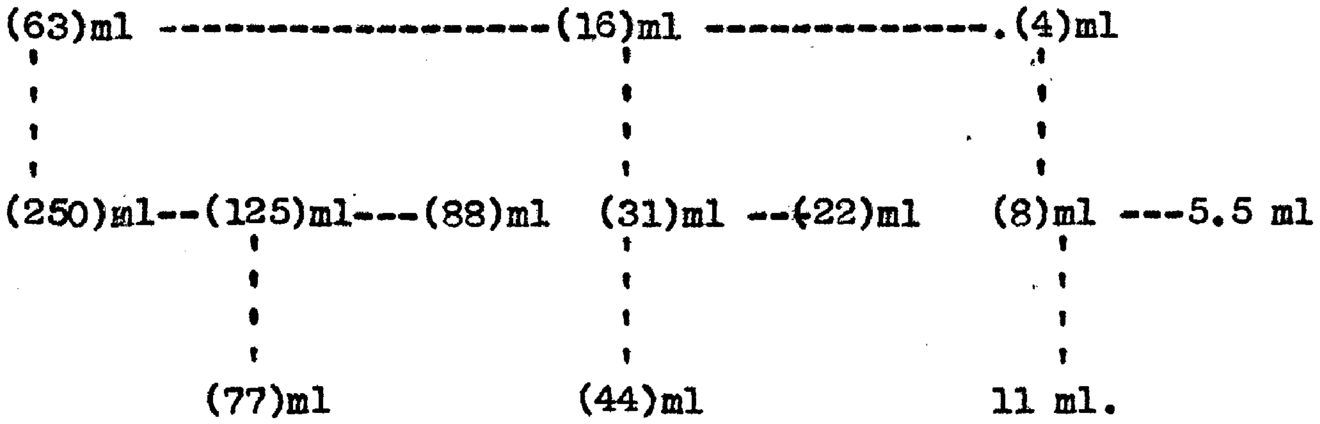
4.3.6. Threshold Odor.

Threshold dilution chart and Threshold odor Table are given below for a 250 ml. sample. If anyother volume is selected by the analyst the values should be modified accordingly.

If odor is present, follow arrow to the right; if odor is absent, follow arrow downward.

Amount of water to be diluted to 250 ml.

Threshold Dilution Chart Table - 1



Threshold Odor Table 2.

Amount of sample diluted to 250 ml.	Threshold odor number.
(250)	(1)
177	1.4
(125)	(2)
88	2.8
(63)	(4)
44	5.6
(31)	(8)
22	11
(16)	(16)
11	22
(8)	45
(4)	(64)

4.3.7. Interpretation of Results.

It is sometimes advantageous to determine both the odor quality and the threshold odor, in which case the results may be combined. For example, a sample which has a distinct odor due to free chlorine and in which the odor is just perceptible at fourfold dilution can be designated as : III Cc 4. Obviously the Roman and Arabic numberals must not be interchanged, for a "IV" quality odor represents water with an odor which forces itself upon the attention, while a "4" Threshold odor may not be at all unpleasant.

4.4. Air Dilution Method

Due to the cumbersome procedure of preparing dilutions as previously outlined above, Professor Gordon M. Fair of Harvard University has developed the Air dilution method which can be followed readily through the use of the Osmoscope.

The principle of air dilution method is to inhale through the special equipment, the atmosphere from above the sample being examined and to admit sufficient quantity of outside air to dilute the odor to a point where it is barely preceptible. In this way, the original sample need not be diluted, unless the odor is quite intense and above the upper calibrated scale of the instrument. In this case original sample would be diluted with odor free water as in dilution with water method explained above.

4.4.1. Equipment

The Osmoscope manufactured by Eimer and Amend consists essentially of two concentric metal tubes fitted at the upper ends with a nose piece. The lower end of the inner tube will project into an Erlenmeyer flask.

The outer tube may be raised and lowered, and in so doing one uncovers holes drilled in the tubes whereby outside air is admitted to dilute the air drawn into the nostrils from the flask. Holes are arranged so that ratio of the volume of air containing the odor from inside the flask to the volume of outside the flask to the volume of outside air may varied in the following steps :

1 : 1; 1 : 2; 1 : 4 ; 1 : 8; 1 : 16; 1 : 32 and 1 : 64.

As mentioned, when discussing the principal of odor determinations, the degree of dilution required to reduce the odor of a mixture of sample and odor free water, or a mixture of air above an agitated sample and the odor free atmosphere, to a barely discernible value, is a measure of the concentration of the odor producing substance. Thus a dilution of 1 to 64 implies that a sample has a concentration of odor producing substance 64 times that required to produce a barely discernible odor having a value of 1. The sense of smell, however, would lead one to judge an odor with a value of 64 as being only 100 percent greater than an odor having a value of 32.

4.4.2. Odor Scale.

Professor Fair, therefore, has developed an odor scale which is based upon this relationship of concentration of odor producing substances and apparent odor intensity, as judged by the sense of smell. It is known as pO scale, that is " potential of Odor". The following table indicate the significance of the scale.

TABLE 3.

Ratio of volume of odoriferous air above sample of water to odorless air from Atmosphere	Degree of dilution		p0 value
1:0 = 2^{-0}	0	0-0 = 0	0
1:2 = 2^{-1}	twice	0x2 = 2	1
1:4 = 2^{-2}	4 fold	2x2 = 4 = 2^2	2
1:8 = 2^{-3}	8 fold	2x2x2=8 = 2^3	3
1:16= 2^{-4}	16 fold	2x2x2x2 = 16 = 2^4	4
1:32= 2^{-5}	32 fold	2x2x2x2x2 = 32 = 2^5	5
1:64= 2^{-6}	64 fold	2x2x2x2x2x2 = 64 = 2^6	6

It is evident that the "degree of dilution" in the table giving the "p0 value" of Fair is equivalent to the odor intensity determined by the above described water dilution method, that is p0 value of 0 is equivalent to a "very faint" odor, a p0 value of 1 to a "faint" odor, a p0 value of 2 to a distinct odor (II) (Art. 4.3.4) etc.

4.4.3. Procedure

1. Place about 100 ml. of the water to be tested in a 500 ml. Erlenmeyer flask and shake.
2. Insert the lower tube of the osmoscope in the flask and adjust to the highest setting of the instrument (p06) giving the greatest dilution with air.
3. Inhale through the nose piece and observe for the apparent odor. If an odor is discernible, its value is p06 (64 on the dilution scale).

4. If no odor is observed with the first setting (p06), adjust the instrument to the next highest position (p05) and observe the odor.

5. Continue untill a barely discerhible odor is observed, and note its value by observing the calibrated setting of the instrument, giving values on the p0 scale.

6. If the odor is very intense, giving values above 6 on the p0 scale, the original sample must be diluted with odor-free water so that the resulting odor is within the range of the Osmoscope. A dilution of 1 to 64 is convinient, that is 1 ml. of the original sample is added to 63ml. of odor-free water. This mixture is then examined in the usual manner.

Assume for instance that 1 to 64 mixture has an odor of 3 on p0 scale. The table 3. indicates that this is equivalent to an eight fold dilution ($2 \times 2 \times 2 = 2^3 = 8$). The equivalent overall dilution, therefore is 8 x 64 or 512 fold. The odor value on p0 scale is 9, because 512 equals 2^9 ($2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 512 = 2^6 \times 2^3$).

4.4.4. Care of Equipment.

The Osmoscope must be clean to insure accurate result. The instrument should be held while in use by the solid rod rather than the adjustible tubes. The instrument should be rinsed with odor-free water, especially after exposure to strong odors. Store in a box when not in use, preferably one containing a canister of activated carbon for maintaining odor free air in the box.

4.5. Standards

The extent to which odor must be reduced in order to produce a uniformly palatable water will, of course, vary, depending upon just how objectionable the specific odor is and just how critical the consuming public may be. Baylis (39) states : "No definite odor threshold figure may be set for the quality of the water desired by the public, but, if the hot odor threshold is more than two, a few consumers with keen sense of smell are able to detect odor". In majority of cases a threshold no of 5 will constitute a palatable water.

The obvious weakness of the "Threshold Odor Test" is that tastes and odors perceptible may be objectionable to one and unobjectionable to other. Thus one of the most pressing problems before the water supply industry is the development of further techniques for the identification and measurement of tastes and odors and substances which cause them. Although it is impossible to itemize all substances causing tastes and odors in water, much of such organic matter is being measured by the Chloroform soluble carbon filter extract (CSCFE). Most of the organic content measured by this method is considered to be from man made wastes, beaause only relatively small amounts of chloroform soluble organic compounds are found in unpolluted lakes and streams as compared to the amounts found in known polluted water.

There is a limited correlation between tastes and odors and the amount of organic compounds in water. It is observed that water free of objectionable tastes and odors in public water supplies have consistently less than 200 ppb of CSCFE compounds (5). This figure of CSCFE may help the operator to judge the possibility of tastes and odor in water supply.

Where taste tests are conducted dilution procedures similar to the threshold odor techniques are employed. Temperature of water is usually kept at tap water temperature, although few plants in U.S.A. do utilise an elevated temperature.

4.6. Value of the Threshold Test.

Running odor tests on water sample from different points in the treatment plant, the operator gets a fairly accurate picture of just how much of odor is being removed.

from the raw water by the various plant processes. Then too, he will learn how much activated carbon should be added to eliminate customer complaints of odor. So long a threshold number of three is not exceeded the regular ~~s~~ small dose of activated carbon sufficient to thus reduce the odor of the water is considered satisfactory and no change is made. Just as soon, however, as a threshold of three is exceeded in the filtered water, the dose of activated carbon to bring down it below three or, if sudden increase in pollution raises the threshold of the raw water quite high, the carbon dose is stepped up before the increase becomes apparent in filtered water.

A correlation between number of threshold points of odor removed per unit dose of carbon can be established for a plant for ready guide to adjust carbon dosages as threshold odor number increases. The co-relation may vary from plant to plant. This divergence is quite likely to be due to the different taste and odor producing pollution in the raw water at different plants, for no two polluting substances are removed by activated carbon on exactly the same ratio; and even in the same water plant, a change in the polluting bodies to be adsorbed and removed by the carbon may immediately change any co-relation which may have been previously set up. Thus threshold test enables plant operator to keep a close control of taste and odor in water and helps in supplying palatable water.

5. SOURCES OF TASTES AND ODORS

5.1. Causes of tastes and odors in a water supply fall in two general classes; natural and man-made.

I. In the first class i.e. Natural Sources are:-

- a) Living algae and other microscopic organisims that contain essential oils and other odorous compounds.
- b) Decaying vegetation like leaves, grass and other organic matter.
- c) Slime forming organisms - actinomycetes in general.
- d) Dissolved mineral matter - sulphur gases and metallic salts from underground sources of water; metallic products of corrosion.

II. The following may be classed as man-made sources :-

- a) Stream pollution by sewage - both domestic and Industrial wastes.
- b) Odors with in plants.
  - i) In connection with disinfection of water - Chlorine and its substituted compounds.
  - ii) Other odors originating in treatment plants.
- c) Taste and odors beyond treatment plants.

I. Natural Sources.

Among the natural causes of tastes and odors, algae are the most frequent offender with decaying vegetation a rather close second. Table 4. shows some results, (contd.)

Table 4 .

Successful Treatments of Tastes & Odors at 241 Plants in U.S.A.

Cause	Plants		No. of plants employing method successfully. *				
	No.	%	Activated Carbon	Free residual Chlorination	Super Chlorination	ClO_2	Aeration
Algae	198	82	163	17	7	6	5
Decaying Vegetation	162	67	139	17	6	6	2
Trade Wastes	92	38	56	12	3	26	3
Others	55	23	47	11	2	3	1

	No. of plants	Percentage employing method successfully *				
Algae	198	82	8.6	3.5	3.0	2.5
Decaying Vegetation	162	85	10.5	3.7	3.7	1.2
Trade Wastes	92	61	13.0	3.3	28.2	3.3
Others	55	85	20.0	3.6	5.5	1.8

* Some plants have employed more than one method

Table No. 5

AMOUNT OF COPPER SULPHATE AND CHLORINE REQUIRED AS LETHAL DOSE FOR VARIOUS ORGANISMS

ORGANISM	Times × reported.	ODOR (TASTE)	Copper suplhate dosage ppm.	Chlorine Dosag ppm.
Diatomaceae	321			
Asterionella	102	Aromatic, geranium, fishy.	0.12 – 0.20	0.5 — 1.6
Cyclotella	29	Faintly aromatic	–	1.0
Diatoma	42	Faintly aromatic		
Meridion	7	Aromatic		
Synedra	93	Earthy	0.36 – 0.50	1.0
Tabellaria	48	Aromatic, geranium, fishy.	0.12 – 0.50	0.50 – 1.0
Cynophyceal	198			
Arabaena	91	Moldy, grassy, vile	0.12 – 0.48	0.50 – 1.0
Aphanizomenon	52	– do –	0.12 – 0.50	0.50 – 1.0
Clathrocystis	12	Sweet, grassy vile	0.12 – 0.25	0.5 – 1.0
Coelosphaerium	29	Sweet grassy	0.2 – 0.33	0.5 – 1.0
Cylindrospermum	5	Grassy	0.12	
Rivularia	9	Moldy, grassy		
Chlorophyceal.	114			
Dicyosphaerium	6	Grassy, nasturtium, fishy		0.5 –1.0
Endorina	16	Faintly fishy	2.0 – 10.0	
Gloeocyrtis	9	offensive		
Hydrodictyon	5	very offensive	0.10	
Nitella flexilis	0	Objectionable	0.10 – 0.18	
Pandorina	17	Faintly fishy	2.00 – 10.00	
Staurastrum	26	Grassy	1.5	
Volvox	35	Fishy	0.25	0.3 – 1.0
Fungi	26			
Beggiatoa	6	very offensive decayed	5.0	
crenothrix	19	medicinal inth chlorine	0.33 – p.5	0.5
Sphaerotilis nataus	1	very offensive delayed	0.40	–
Protozoa	205			
Bursaria	0	Irish moss, saltmarsh, fishy	0.24 – 0.33	0.3 – 1.
certainm	33	Fishy, vile	0.5	
Cryptomones	16	Candied nolets		
Dinobryon	48	Aromatic, violet, fishy	0.18	9.3 – 1.
Glenodinium	13	Fishy	0.50	
Mallomonas	23	Aromatic, Violets, fishy	0.50	
Peridinium	16	Fishy like Clamshells	0.50 – 2.00	
Synura	66	Cucumber, muskmelon, fishy (bitter taste)	0.12 – 0.25	0.3 – 1.

× Results of survey conducted in U.S.A by Ralph Porges. (1)

in combating a particular cause of odor. Therefore the total number of instances of successful treatment may exceed the number of plants reporting the specific cause.

+ Percentage figures are based on number of plants reporting a particular cause, not the total 241. A total of percentage in any given row may exceed 100%.

as a result of survey conducted in U.S.A. It will be seen that algae are reported by 82% and decaying vegetation by 61% of plants. In worm surface waters, the bacterial slimes may creat even more serious troubles. These slimes may grow on rocks in open channels, in surface reservoirs and on the sides of transmission and distribution mains; Research by Silvery and Roach (11) indicate that aquatic actinomycetes (filamentous mold-like organisms) are responsible for a large proportion of the tastes and odors, that occur sporadically in surface supplies, and which were formerly attributed to disintegrating organic matter. Hydrogen sulphide is the most common sulphur gas, thnough sulphurdioxide gas is also sometimes found in ground water and results in odors. Iron, manganese, copper and zinc are common metals found dissolved in water and may impart taste to water.

5.2. Algae

Practically every surface supply is likely to be faced with algal growth in sufficient concentration to cause objectionable odors. There are thousands of types of algae, so that it is possible for the water plant operator to became acquainted with only a few of the more predominant types which cause tastes and odors in water supplies. Many of these organisms if allowed to complete their life cycles or if killed after attaining growth, exude oils or decomposition products which impart disagreeable tastes and odors to the water. With the aid of a microscope, the average operator can easily learn to recognise the worst offenders and to judge the necessity of applying preventive or corrective treatment. Table No. 5. gives the type of algae and other organisms which were found to cause tastes and odors. This report (1 & 9) was published as a result of survey conducted on 570 plants in U.S.A. This algae questionnaire, used in survey, also asked whether there was any disagreement as to characteristic of odor associated with individual type. Predominantly there was agreement with the characteristic odors with a few exceptions as follows :-

1. Asterionella: A number of plants reported experiencing the fishy odors without encountering the aromatic or geranium odor.
2. Anabaena: One reported this to give geranium odor, while several reported the odor to be pigpen.

3. Apharizomenon: Several different descriptions were offered for odors associated with this type, including nasturtium, pigpen, dry musty, and corn husks.
4. Ceratium: Several described the odor as cod liver oil and bitter.

5.3. Decaying Vegetation

Odors under the classification of decaying vegetation derive from: decaying algae; leaves; weeds or grass; seepage from stagnant areas into reservoirs or streams; flushing of stagnant area and farm lands during spring freshets or heavy rainfall periods; and any disturbance of bottom deposits in streams or impounded supplies due to sudden raising or lowering of water level.

Data available from survey conducted in United States is tabulated in Table 6. It will be noted that most prevelent descriptive term is musty, while the anticipated descriptions of swampy, wet leaves and moldy, fall far behind. A close examinations of the descriptive terms at the bottom of Table 6 will indicate the imaginative character of some observers. It is quite possible that many of these odors may actually be due to presence of actinomycetes.

Table 6.

Odor Types Due to Decaying Vegetation *

Characteristic Odor	No. of Plants reporting
Musty	69
Earthy	28
Woody	20
Moldy	17
Swampy	12
Grassy	9
Fishy	8
Wet leaves	7

* Other mentioned to less degree are septic, muddy, boggy, vegetable, phenol, peaty, rotten, putrid, soaked straw very som, varnish, barnyard and horse urine.

5.4. Actinomycetes

Support from water works operator is wanting to generlise any statement about taste and odors caused by actinomycetes.

Streptomyces * has been found offender and

[illegible]

satisfies several of requirements of earthy, musty odor producing agents in raw water. Bacterial growths also impart tastes and odors to water, either by waste products of their own metabolism or by the transformation of certain inorganic substances. The same are very common in the dead ends of the distribution system and other water conveyance pipes where the velocity of water is low. Based on J.K.G. Silvery (11) reports, actinomycetes are responsible for many odors encountered in raw water supplies. In fact it has been indicated that many of odors attributed to algae are actually caused by growth of actinomycetes present in water. But due to lack of equipment in water works laboratories, no such data is available to support these findings in laboratory.

* Streptomyees :

A. genus of the odor actinomycetes.

B. Commonly referred to as one of actinomycetes (14)-

5.5. Mineral Matter

The presence of dissolved minerals in underground water supplies poses a taste problem in some water supplies. A great majority are caused by the dissolving of minerals from the underground strata, resulting in high chloride, sulphates, hydrogen - sulphide, manganese and Iron contents. Also some few cases of salinity due to salt water incrustations have occured. A great majority of water giving difficulty with Iron and hydrogen sulphide are treated suitably by aeration, followed by either chlorination or retention for complete oxidation. No economically successful treatments have been devised for chlorides and sulphates bearing waters. Some communities develope tolerance for slight mineral tastes but where such tastes are very severe, these supplies are almost abandoned in favour of more palatable ones.

5.5.1. Taste experiments conducted with tap water by Stoof (17) in 1918-19 year reported.

1. The limits of perception are lowest for ferrous ions and highest for potassium salts.
2. The anions can be arranged in order of increasing taste threshold as OH^-, NO_3^-, Cl^-, HCO_3^-, SO_4^{--}.
3. The cations can be arranged in order of threshold as Na^+, Mg^{++}, Ca^{++}, Fe^{++}, Mn^{++} and
4. Ammonium ion is characterized in all its salts by a low threshold, and potassium

hydroxide in contrast to its salt, is easier to recognise.

Taste imparting concentration of most commonly occuring metals in water have been studied by various authors. Below are given the findings.

5.5.2. Copper

Schneider suggested that admissible amount of copper in water be set at 5 ppm as a greater content will give a disagreeable taste to water. Spitta stated 2 ppm of copper was taste threshold concentration. Forboese, on the other hand, reported that 1.5 ppm was the lowest concentration of copper that normally could be tasted.

5.5.3 Zinc

Drinker and Fairhall reported that a panel of ten men and ten women judged, the taste of $ZnSo_4$ in distilled water, with these results; 2 detected the taste at 10 ppm, 4 at 37 ppm, 10 at 73 ppm and remaining at 156 ppm, The taste was described as astringent. Anderson, Renihard, and Hammel stated that 40 ppm of zinc gives water a milky appearance and provides an astringent taste. 30-40 ppm is the reasonable and safe in drinking, with taste not objectionable at the maximum levels, limits as suggested by Hegstedt, Mcklibben and drinker.

5.5.4. Iron

Lockhart, Tucker and Merritt found 10 ppm to be the taste threshold of ferric Iron added to distilled water as $Fe_2(SO_4)_3$

Results of Recent Works (62) on taste threshold concentration of metals in drinking water are given in Table 7 .

Table 7

Taste Threshold for Metal in Water.

Metallic Constituent	* Threshold frequency in distilled Water	
	50%	50%
	Iron concen-	tration ppm.
$ZnSO_4$	4.3	18
$Zn(NO_3)_2$	5.2	22
$ZnCl_2$	6.3	25
$CuCl_2$	2.6	6.6
$FeSO_4$	0.04	3.4
Hydrous ferric Oxide.	0.7	8.8
$MnSO_4$	3.6	45.0

* Threshold values are for the metal ions, not the salt.

5.6. Deoxygenation

The Summer stratification of deep reserviors often curtails the use of deep waters and creates taste and odor problems in late summer and fall. In a survey conducted in U.S.A. (1) on 159 plants only 31 reported having such odor problems. Many of the reporting plants however, derive their water from stream and shallow water reservoirs, where such problem would not exist. These problems become especially troublesome in older reservoirs where existing outlet structures are not versatile enough to permit such reservoirs avoidance of the water strata which have become objectionable. Such reservoirs which have required special attention are those at Encino and Lower Hollywood. According to some comments, a flat, earthy tastes developed under a heavy ice coating at several locations due to deficiency of oxygen. Many plants reported development of Septic or hydrogen sulphide odors and some a swampy odor. One plant reported that a cool rain and hail storm broke up thermocline giving rise to fishy, haylike, musty and earthy odors.

Fig. 5 shows typical conditions at the Lower Hollywood reservoir. The graphs in the centre of the chart show temperature and depth relationship at different periods of the year. The circulating zone, or

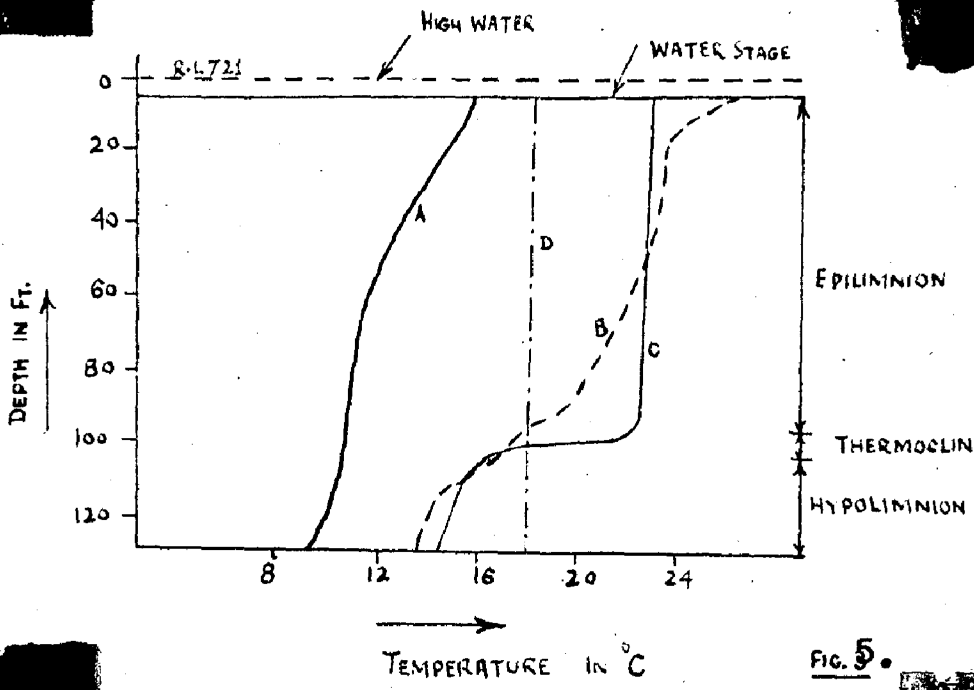


Fig. 5.

Curves indicate temperature changes at various stratifications for following days of test:

Curve A,	March 5.
Curve B,	July 16.
Curve C,	Aug. 26.
Curve D,	Nov. 6.

epiliminon, gradually increases in temperature through the spring and summer, resulting in the formation of a narrow stratum characterised by sharp temperature differentials. This layer is called the transition zone, mesolimnion, or thermocline, and then effectively prevents the stagnation zone, or hypolimnion, from replenishing its oxygen supply.

The hypolimnion is the problem zone, shut off from a source of DO by the thermocline, the hypolimnion suffers oxygen depletion, which result in anaerobic decomposition of organic debris such as dead algae, aquatic weeds, leaves, and dead fish. This causes tastes and odors, produces a more acid envoirmment, promotes sulphide formation, and results in increased ammonia, phosphates, nitrogen and various metallic constituents.

Table 8 .

Water Quality Deterioration During Stratification
Lower Hollywood Reservoir a/
1953.

	Concentration ppm		
	April 11	June 9	October 2
DO	9.1	0.0	0.0
Sulphide	0.0	2.8	10.1
NH_3	0.2	3.8	13.0
TKN *	0.6	4.8	15.1
Phosphate	0.4	2.7	5.8

a/ Samples taken at Cl 590

* Total Kjeldahl nitrogen.

Table 8. shows progressive changes in water quality during stratification at the Lower Hollywood reservoir. The tremendous increase in the products of anarobic decomposition below the thermocline is readily noted. These changes deteriorate water quality because excessive tastes and odors will enter the circulating zone during the fall equilization. Increase in phosphates nitrogen and ammonia, as a result of anaerobic action, also add to the already burdensome algae, problems which in turn adds to taste and odor problems.

II MAN MADE SOURCES

5.7. Industrial Wastes and Others.

Industrial wastes are less frequently the cause of taste and odors, but when they do cause trouble they are likely to create very severe taste problems and odor conditions. The ever increasing industrial activity has resulted in greater pollution of streams, thereby accentuating the problems of delivering a palatable water from such sources. Among the industrial wastes which cause odors in water supplies are those of : organic chemical plants (dyes, medicinals, plastics etc.); oil refineries; canneries; sugar beet plants; dairies; distilleries; slaughter houses; tanneries; byproduct coke plants; synthetic rubber plants; and plup and Paper mills.

Table 9. shows types of trade wastes causing tastes and odors in water supplies. Phenol is reported most frequently, with chemical second.

Table 9.

Frequency of Trade Wastes Causing Odors *

Types of Waste	No of Plants Reporting
Phenol	38
Chemical	20
Petroleum oil or Oil refinery	18

* Other less frequently mentioned are dairies, Corn sugar plants, canneries, mine wastes, Sulphite paper mills and Vitamin wastes. These results are as a result of survey conducted on 241 plants in U.S.A.

The most frequent listing in the classification of other causes is sewage with 22 reporting. Second is the muddy earthy type odor associated with high turbidity, with nine reporting. Less frequently listed are synthetic detergents, actinomycetes, dairy farms, fish and silt deposits.

Table 10

Concentrations of Some Chemicals Causing Tastes and Odors

Substance	* Concentration detectable p.p.b.
Formaldehyde	50,000
Picolines	500 - 1,000
Phenolics	250 - 4,000
X ylenes.	300 - 1,000
Refinery hydrocarbon	25 - 50
Petrochemical wastes.	15 - 100
Phenylether	13
Chlorinated phenolics	1 - 100

* Concentrations were determined by taking the median of 4 - 12 observations.

Tastes and odors from such wastes are almost caused by organic substances. Some of the chemicals isolated from water, along with the concentrations (17) which can be detected by odor are given in Table 10 . On of the most objectionable compounds sometimes found in industrial wastes is phenol or phenolic types of compounds, found in wastes from by-product coke ovens. These phenolic bodies in the presence of chlorine react~~s~~ to form, chlorine derivatives of phenols which are very odorous compounds and are detectable in very low concentration as the figures in the Table 11. confirm.

Tests made by Howard Showed that iodoform tastes were observed in the filtered water with a phenol content of 0.006 ppm after chlorination with 0.2 ppm of chlorine. Authorities differ as to the concentration of phenol necessary to produce tastes when water is chlorinated. Thresh reported that as little as 0.0002 ppm of phenol with 0.25 ppm of chlorine produced a taste (63, p 516).

5.8. Odors with in Plants

A. 5.8. Taste & Odor Due to Chlorine

High chlorine residuals result in chlorinous tastes & odors, while break point chlorination may result in formation of nitrogen trichloride which gives very underisable medicinal odors to water. Combination of chlorine with synthetic detergents used in modern household have also caused odors & tastes. The most vital taste & odor are produced by chlorination of phenols present in water due to industrial pollution of raw water. Same are discussed in detail below.

5.8.1. Chlorinated Products of Phenols. (Chlorine Substituted compounds)

Maximum taste producing potentials develops only after chlorination of phenol. The chlorination products of phenol in water supplies have been the subject of much conjecture. Due to the evident similarity of tastes, Adams suggested (21) that taste of chlorinated phenol is caused mainly by 2 chlorophenols (2-CP). Ettinger and Ruchhoft presented conflicting data.

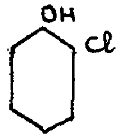
1. The molecular ratio of Cl_2 to phenol required to develope maximum taste is about twice that required to form 2 - CP.
2. The taste intensity of chlorinated phenol is greater than that of an equivalent concentration of 2- CP.
3. Further chlorination of 2-CP produces an intensification of the taste. The widely accepted principles of orientation of aromatic substitution indicate that progressive

chlorination of phenols proceeds through the stages of 2 & 4-CP , 2, 4- dischlorophenol (2,4-DCP); 2,4,6-trichlorophenol (2,4,6-TCP); and more highly chlorinated products.

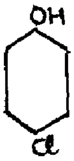
The structures of the compounds are

Phenol

2-CP

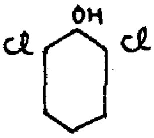


4-CP

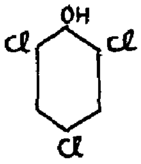


2,4-DCP

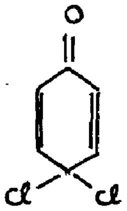
2,6-DCP



2,4,6-TCP



4,4-Dichloroquinone



From their results Ettinger and Ruchhoft (22) concluded that none of these compounds could account adequately for tastes of chlorinated phenols. Ingols and Ridenour also rejected these compounds as the key causes of taste in chlorinated phenols and suggested instead that a dischloroquinone is characteristic product (23).

All of the chlorination products, it has been determined, may contribute to the intensity of taste and odor. At maximum taste and odor intensity the major contributor is a hitherto overlooked compound : 2,6-DCP. The series of reactions leading to the formation and ultimate destructions of the chlorination product involves complex kinetics relationships. These kinetic factor probably provide the explanation for some apparent chlorination anomalies, such as reported instances in which phenol pollution either did not result in taste formation or in which the occurance of taste was markedly delayed.

5.8.1.1. Taste and Odor Thresholds of Chlorinated Phenols

The results (16) are shown in table 11. Panel of four to six observers were used.

Table 11

Taste & Odor Threshold Concentration *

Components	Geometric mean Thresholds ppb	
	Taste	Odors
Phenols	1,000	1,000
2 - CP	4	2
4- CP	1,000	250
2,4-DCP	8	2
2,6-DCP	2	3
2,4,6-TCP	1,000	1,000

* All tests were made on room temperature about 25^{o} C.

The table shows that the relative contributions to taste and odor by phenols, 4-CP, & 2,4,6-TCP are negligible. Application of the approperiate threshold data to the estimated (16) composition of chlorinated phenol solution in laboratory (chlorine to phenol wt. ratio 2:1 for maximum taste development) indicated that 2,6-DCP contributed about 75% the total taste and 2,4-DCP and 2-CP contributed the remainder.

5.8.1.2. Governing Conditions.

The development, absence or disappearance of tastes and odors depends upon suitable combination of certain factors.

a) Chlorine

Ettinger and Ruchhoft (22) found that the addition of 4 ppm of Cl_2 to 1 ppm of phenol at pH 8 resulted in destruction of taste, but 7 ppm Cl_2 was required to produce a free residual. Investigation of nature of products resulting from increased chlorination by ultraviolet spectrophotometry revealed the disappearance of aromatic characteristics with increasing Cl_2 dosage.

b) pH

Typical development of chlorophenolic taste does not occur at less than pH 7 . The optimum pH value is 8. To demonstrate (16) this a series of solution containing 10 mg. phenol in 500ml of $NaH CO_3$ buffer solution were treated with 20 mg. chlorine. Chlorine residuals was determined after 2 & 20 hrs. The phenolic chlorination products were identified with infrared spectra after extraction. The results are given in Table 12 .

Table 12.

Effect of pH on Chlorophenolic Products

pH	Chlorine Residual ppm		Components detected
	2 hrs.	20 hrs.	
6.0	0.05	0.05	phenol; traces of 2-CP& 4-CP
8.0	0.05	0.05	2,4,6-TCP; much 2,4-& 2,6-DCP traces of phenol, 2-CP & 4-CP
9.0	0.15-0.20	0.05	Same as for pH 8 except less 2,4,6-TCP.
10.0	0.50	0.1 -0.15	Same as for pH 9.0

Negligible chlorination occured at pH 6.0; at pH 8.0 and higher the reaction products and tastes thresholds were virtually identical, however, the higher chlorine residuals at pH 9.0 and 10.0 indicate that the maximum rate of chlorination occur at pH 8.0.

c) Ammonia

It is known that presence of ammonia in phenol solution inhibits the formation of the chlorophenolic taste, probably by consuming the chlorine in the formation of chloramine (2,4). Laboratory tests conducted (16) in presence of ammonia between phenol & chlorine solution showed almost unreacted phenols after 18 hours. Where as after 5½ days the mixture developed typical chlorophenolic tastes due to presence of significant amounts of 2,4- & 2,6- DCP.

d) Ammonia & pH

The combined effect of NH_3 and pH on the rate of chlorination of phenols is also studied (16). Formation of 2,6-DCP is slow at pH 9, slightly faster at pH 8 and not at all at pH 6.

The results indicate that the same course of chlorination (Fig 6.) which results in product of intense taste occurs in the presence of NH_3 , but much more slowly. Under suitable conditions this phenomenon may result in a "medicinal" taste which will be apparent to water consumer even if it is not detectable at water plant.

OF CHLORINATION OF PHENOL.

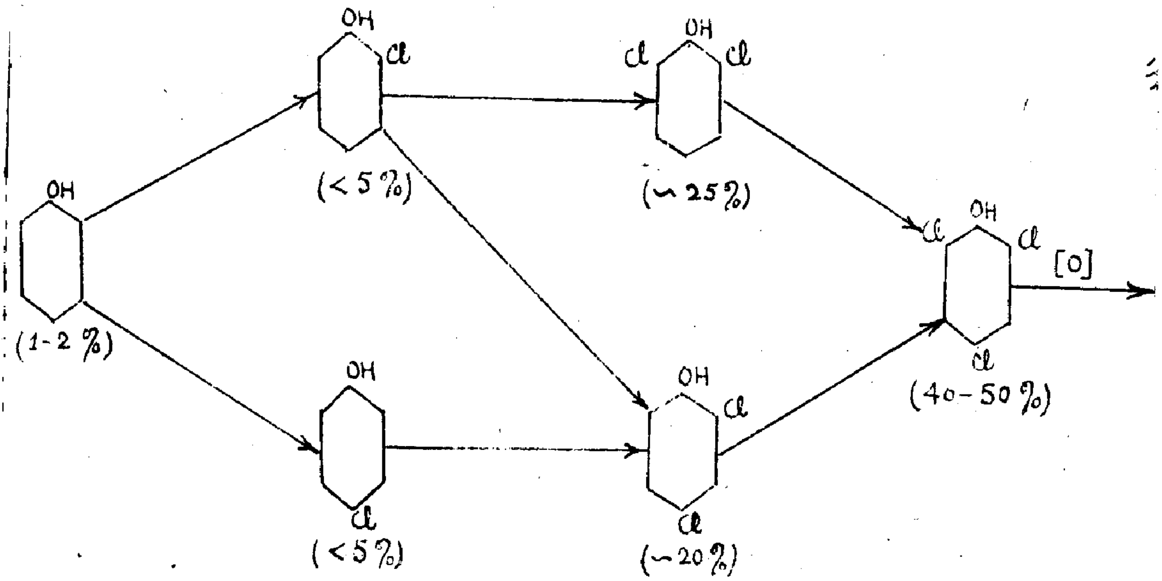


FIG. No 6.

[redacted]

[redacted]

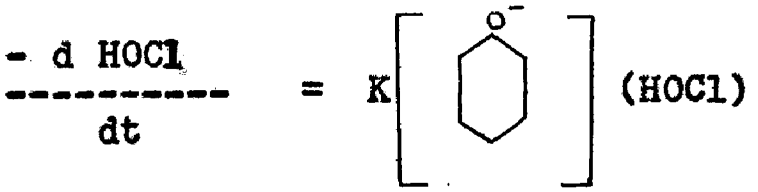
[redacted]

Course of chlorination of a 20ppm. phenol solution reacted with 40 ppm. Chlorine, at pH 8. The parenthesized figures refer to the approximate amounts present after 18 hrs.

6.8.1.3 Discussion & Conclusions

The chlorination of phenols proceed by progressive substitution of available ortho and para positions (fig 6.) Several taste-producing substances and other relatively nontaste - producing substances and other relatively nontaste - producing ones comprise the mixture of chlorination products. Earlier efforts failed to establish the identity of products from the molar ratio of chlorine to phenols because of a number of concurrent and consecutive reactions which take place, involving extremely complex kinetics relationships. These kinetic relationships are influenced by the usual factors of concentration and temperature and by pH and ammonia concentration. Certain combination of these factors may prevent or retard the detectable on set of chlorination reaction. These combinations are probably the cause of some inconsistent observation made on polluted streams containing both phenol and ammonia (25).

Comparatively little information on the kinetics of chlorination of dilute phenol is available in the literature. Soper & Smith (25) have studied the reaction in neutral basic media at concentration of the order of 10^{-3} M and have found kinetics depending on concentration of phenoxide ion and undissociated hypochlorous acid which are the reactive species.



$$\frac{-\,d\ HOCl}{dt} = K\left[C_6H_5O^- \right](HOCl)$$

This equation agrees with the observations that pH increases from near neutrality the rate of reaction increases to a maximum and then decreases.

According to Soper and Smith, molecular chlorine is the most probable chlorinating agent under acid conditions and is produced in the equilibrium.

$$HOCl + HCl \rightleftharpoons Cl_2 + H_2O$$

De la Mare, Ketley and Vernon (26) reached the same conclusion about the significance of molecular chlorine at low pH. According to their conclusion phenol would also then react in its unionised form. Therefore, the mechanism of chlorination would be quite different from what it would be under alkaline conditions. As a consequence not only the reaction rate but also the properties of chlorination isomers produced might differ markedly according to pH.

The mechanism of the reaction of chloramine with phenol has not been investigated. It is not known whether chloramine itself is the chlorinating agent or whether it slowly librates HOCl or Cl_2 by hydrolysis to effect the chlorination. Either mechanism could account for the fact that chlorophenols are produced very slowly and that the retardation of chlorophenolic taste in the presence of Ammonia is a kinetic phenomenon.

B. 5. 8. Other Odors Originating in Treatment Plant.

Only about 30% of 159 reporting plants in United States reported the development of odors with in treatment plant. The greater majority reported facing difficulty with decomposing sludge in settling basins. Algae have been reported to develope in presettling basins, and pose a taste and odor problem. Very few reported any problem with odor development in the filter. Instances involved overchlorination of water entering the filters and algae or decomposing sludge on filters. One report indicated that application of ammonia ahead of filteration, followed by part chlorination gave rise to a serious algae problems in filter. The reason put forward by Babbit is the possible oxidation of NH_3 to nitrates which help in algae growth. This was corrected by moving the point of application of chlorine ahead of filters. Isolated examples of odor development within the treatment plant include improper combustion of CO_2 producers, temperature turn over of water in basins, recirculation of primary sludge, and lime softening giving a strong fishy odor.

The greater number 69% of 159 plants, during survey conducted in U.S.A., reported development of odors or tastes due to treatment chemicals. 79% of plants having these problems reported chlorinous odors. 39% reported Medicinal odors due to chlorophenols and 15% due to NCl_3. Other chemical influences were chloralgal odors, fixation of odors by lime, hop odor from CO_2 and bitter taste due to chlorine reaction with detergents.

5.9. Tastes and Odors Beyond Treatment Plants

Of 159 water supplies reporting, only 49% reported having problems of taste and odor arising in distribution systems. The preponderance of odor problems within distribution system occurs in what is classed as low flow areas and in dead ends. The quality of water in these areas often may be worse than the raw water as far as tastes and odor are concerned. Less than 15% of these reporting indicated problems caused by pipe lines. Of very minor significance is the development of odors in new Iron or cement pipes, sloughing off deposits, tank coatings and disinfection procedures on new distribution lines.

6. PREVENTIVE TREATMENT

Treatment for taste and odor control involves two main types of attack -- that of prevention and that of correction. And water supplies are not immune from the truth of old adage " An ounce of prevention is worth a pound of cure". As a matter of fact, proper preventive treatment by use of such materials as copper sulphate, chlorine and activated carbon offers more than mere economic advantages in assuring a better-quality product as a result of better raw material. And though preventive treatment is, of course, most effective at the source, it can be applied advantageously at almost any point in the system.

6.1. Impounded Supplies

Impounded supplies are seldom subject to industrial or domestic pollution, but quality of water stored is often impaired by swampy areas and other natural polluting agents. Swampy areas give rise to stagnation type odors and other undersirable characteristics as color. Similarly, the leaves from deciduous trees cause not only odors but such other difficulties as color and the clogging of screens; and aquatic plants and animals in their very life process are agents of water quality impairment.

As measures of prevention, swampy areas should be filled in, dammed off or other-wise eliminated; coniferous trees should be cultivated, at least in areas immediately surrounding impounded supplies; and aquatic plant and animal life should be kept under control.

In deep reservoirs summer straitification takes place. The hypolimnion zone (Art. 5.6.) suffers from oxygen depletion and becomes cause of taste and odor due to anaerobic decomposition of organic matter taking place there. Chlorination of troubled zones of deep reservoirs at lower Hollywood has greatly reduced the taste and odor problems and can be looked as a successful method for remedying taste and odors in deep summer stratified reservoirs .

Algae are the most frequently offensive aquatic growths from the view point of palatability and, thus, should be kept minimum at all times. Since one of the requisites for their propagation is sunlight, impounded waters (which are relatively free of turbidity), open coagutaling tanks, settling basins, open clear wells or distributing reservoirs are specially subject to such growths. Frequent examination of the supply for identification and determination of the density of algae present should be routine; and results of such tests should be

IMPOUNDING RESERVOIR CONTROL

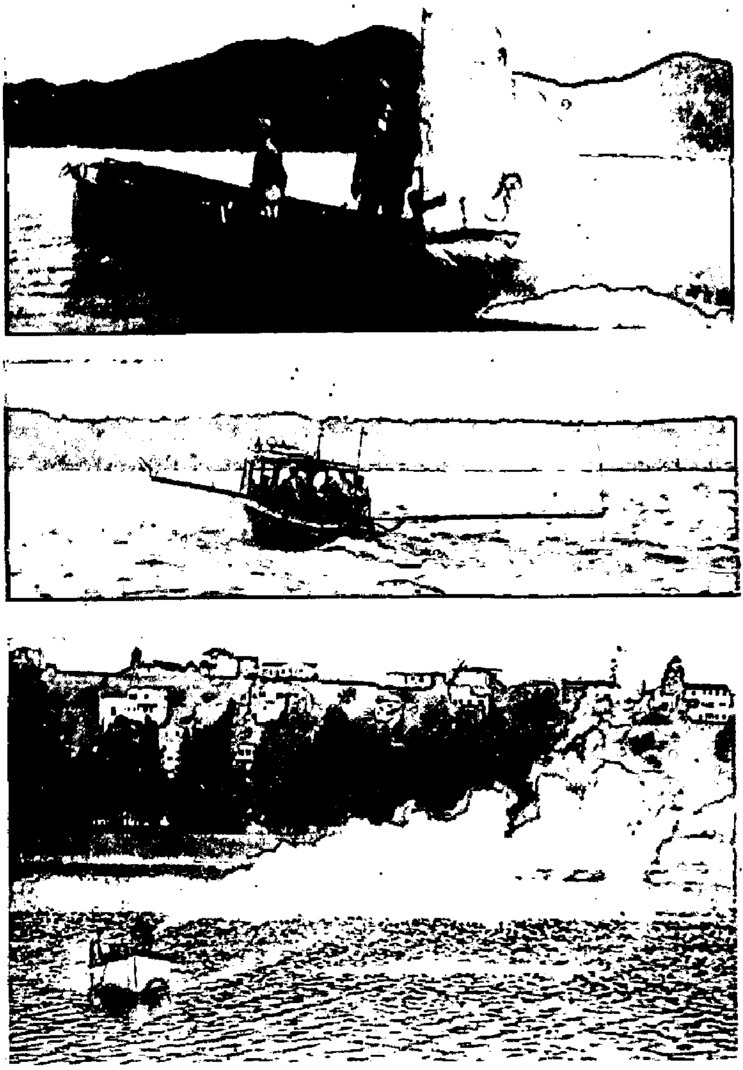


Fig. Three Types of Copper Sulfate Feeding Apparatus
Top: Goudey "Broadcaster" Type
Middle: Extended Arm Type, used at Syracuse, N.Y.
Bottom: Blower Type, showing how distribution is aided by wind carriage

Figure. 7.

used as a guide for the treatment with copper sulphate, chlorine or other algicides. For lethal dosages of $CuSO_4$ and Cl_2 required for different types of organisms (including algae), Table 5. can serve as a guide. Research has revealed that copper sulphate residuals, altered some biological mechanism of streptomyces (one of actinomycetes Art 5.5.) which was found offender and satisfies several of requirements of earthy, musty odor producing agents in water. Copper sulphate (13) residuals to control earthy, musty odors in water supplies has been supported by a number of practical experiences in the field specially Los Angeles aquaduct water supplies. Some of the methods of applications of Copper Sulphate to impounded reservoirs are shown in figure 7.

Details of methods can be referred to (9) page 118. Close attention to these details will prevent algae growth from reaching concentrations which will cause taste and odor difficulties and will appreciably relieve the necessity for later corrective treatements.

Complaints usually arise when the concentration of microscopic organisms exceeds 1,000 standard units, although some types, such as Synura, may cause difficulties in lower concentrations. When the organisms die, minute quantities of unsaturated oils are released and these oils in turn, intensify the tastes and odors present. Further more, it has been found that application of Chlorine in amounts less than that required to oxidise these compounds completely may tend to increase still further these taste and odor intensities.

7.2. River and Stream Waters

River and Stream Waters also suffer some impairment of quality from the effects of natural polluting agents, and, though the elimination of such pollution is often impractical, serious consideration should be given to the possibility of draining swamps, cutting weeds and controlling algae growth. Object of the most effective preventive action, however, are the discharges into rivers and streams by industrial plants and domestic sewage works, which frequently are the cause of taste and odor conditions much more difficult to combat than those caused by natural pollution. Action to promote treatment of domestic sewage before it is discharged into streams is important not only from the view point of palatability but from that of safety. Trade wastes which are objectionable because of their effect upon palatability should, whenever possible, be segregated and kept from entering any stream used as water supply source. Frequently such objectionable wastes constitute only a small part of the total wastes discharged and can, thus be collected in water tight containers, be disposed of later in such a manner as not to produce tastes and odors in water supplies. In notable instances, too, industrial plants have been successful in reclaiming valuable chemicals from such objectionable wastes or in employing the wastes directly in developing by -products, thus making participation of the industry in a taste and odor control programme economically, as well as socially, justifiable. In a nutshell, enforcement of well calculated stream pollution by-laws will help to prevent this, socio-economic problem of taste and odor in water supplies from streams and rivers.

7.3. <u>Within the Water Treatment Plant itself</u>, preventive measures can be utilized to considerable advantage. Settling basins should be cleaned at frequent intervals to eliminate sludge which may decompose and impart an objectionable odor to water. Installation of sludge removal equipment, feeding activated carbon or chlorine at the basin influent and addition of carbon when refilling basins are other corrective measures.

In settling basins, after coagulation, the water is usually relatively free of turbidity and, therefore, in an ideal condition for algae development. Suitable measures for the prevention of algae growth, such as regular treatment with copper sulphate, chlorine or activated carbon, are thus indicated.

Since approximately 1930, ammonia in combination with chlorine has been used for preventing tastes and odors, particularly those of phenolic type. The value of this type of treatment lies in the fact that when free ammonia (NH_3 -N) is present in water, the chlorine will react with ammonia before reacting with the organic compounds. Excess of ammonia is essential and must be added ahead of chlorine. It is important that the ammonia be applied at the right point and that adequate mixing and time of contact be provided before the application of the Chlorine, this time should be between 20 minutes and 1 to 2 hr. The ammonia may be applied at any convinient point, an open reservoir or a closed conduit, where the efficacy of application has been proved by experience. Because the ammonia dissolves quickly in the water but does not diffuse readily, it should be mixed by mechanical means. It should be released near the bottom of a reservoir, because its specific gravity is less than that of water.

The period of contact must not be made too, long, because the ammonia is a food for mitrifying bacteria which may remove the ammonia before it is available for the action of the chlorine resulting in an increase in the bacteria and nitrate content of filtered water. The resistance of these bacteria makes it appear impracticable to control nitrification by chlorination. If insufficient chlorine is added to carry a residual through filters, the addition of more chlorine will probably cause tastes, as chloramines donot remove phenols from water, and post addition of chlorine, un= protected by ammonia will cause phenol tastes (6.3 . p520)

The quantities of ammonia required as NH_3 normally vary from a third to a quarter of chlorine requirements, though in extremes, ratios as high as 1 : 1 may be used. Since chloramine formation is slower in the acid range than in the alkaline range, better results are obtained in supression of chlorophenolic taste and odors at pH values greater than 7.0 where chloramines are formed before undersirable chlorophenols develope. It should be pointed out that the chlorine - ammonia treatment is preventive, and will not remove tastes and odors once they have formed.

Another point at which preventive treatment can be applied is at the sand filters which may be subject to organic growths like algae and others in Schmutzdecke (specially in slow sand filters) that on decomposing will exude essential organic oils. These oils will impart taste and odor to the water. Thus it is extremely important that filters be kept clean at all times by some such means as washing the filter sand with chlorine at frequent intervals. Such regular practices should be followed on gravity and pressure type filters, but extreme caution must be observed in using chlorine solution for treatment of slow sand filters, particularly if they may have accumulated a heavy organic load over a long service period. Mechanical cleaning devices such as the 'surface wash' and 'filter sweep' are invaluable aids for maintaining filter in good condition.

7.4. Beyond the Treatment Plant, too, extreme care must be taken to prevent redevelopment of odors in the water. It is apparent that while an acceptable water is produced at the plant some change in quality takes place by the time it reaches a consumer located on a dead end or in low flow area. As consumers in these areas are estimated by Don B. Williams at Brantford, to represent 30% or more of consuming public. The problem involved is one of magnitude.

Treatment should be such as to prevent slime growths in the distribution system. Maintenance of chloramines or chlorine residuals are a remedy. It is experienced that in absence of organic nitrogenous matter free chlorine and chloramine residuals are equally stable all other conditions remaining equal. But, in presence of protein matter, it is advisable to leave chloramine residuals as free chlorine residuals are unstable. Correction of pH, oxygen and carbon dioxide content of water also helps to prevent tastes at consumers taps by avoiding corrosion of pipes. Other possible corrosion preventive devices should be incorporated.

The preponderance of odor problems with in the distribution system occurs in low velocity areas and are successfully corrected by a flushing programme.

Where possible, distribution reservoirs should be covered as a protection against contamination by algae.

7. CORRECTIVE TREATMENT

Corrective treatment for taste and odor control usually takes place at the treatment plant itself, and is ordinarily applied in conjuction with preventive methods. Their correction is often a part of treatment processes that serve other primary purposes. Coagulation, sedimentation, filteration, are examples. But there are certain processes in which odor and taste removal or control is the principal objective or the specific purpose. These corrective treatments may range from simple aeration to complicated processes involving the use of both equipment and chemicals. The most common practices, in addition to aeration, include application of coagulants, activated carbon, chlorine (prechlorination, superchlorination follwed by dechlorination) chlorine in combination with ammonia or (Chloramination) ozone, chlorine dioxide and bleaching clays. Survey conducted by Ralph Porges (8) IN U.S.A. reported the overall effectiveness of corrective measures as follows:

Activated carbon - 86%, ClO_2 - 25%; superchlorination & dechlorination - 23% ; free residual chlorination - 17% and aeration 9%. The detail diagonosis of success of various corrective measures used, for different cause of taste and odor, in this survey

TABLE NO. 13.

DEGREE OF SUCCESS WITH CORRECTIVE TREATMENTS, REPORTED BY 241 US PLANTS *

Causes of Odors	No. of Plants reporting	Activated Carbon (221)						Free Residual Chlorination (158)						Superand Dechlorination (34)						Chlorine Dioxide (70)						Aeration (55)					
		Total		Partial		None		Total		Partial		None		Total		Partial		None		Total		Partial		None		Total		Partial		None.	
		No.	%	No.	%	No.	%	No	%	No	%	No.	%	No.	%	No	%	No	%	No.	%	No	%	No.	%	No.	%	No.	%	No.	%
Algae	198	163	90	17	9	2	1	17	13	56	44	54	42	7	24	12	41	10	34	6	13	12	25	30	62	5	11	24	53	16	36
Decaying Vegetation	162	139	92	11	7	1	1	17	16	46	43	48	41	6	30	35	25	9	45	6	14	8	19	28	67	2	6	18	47	18	47
Trade Wastes	92	56	68	23	28	3	4	12	19	22	35	28	45	3	17	6	33	9	50	26	49	13	24	14	26	3	14	9	43	9	43
Others	55	47	87	5	9	2	4	11	28	12	31	16	41	2	20	3	30	5	50	3	14	2	10	16	76	1	7	7	50	6	43
Overall Summary	507	405	86	56	12	8	2	57	17	136	41	142	42	18	23	26	34	33	43	41	25	35	21	88	54	11	9	58	49	49	42

* Percentage figures are based only on those plants that reported having tried the specific treatment on the particular cause of odor. For example, on other causes of odor, chlorine dioxide was tried by 21 plants; therefore, percentage calculations were based on 21, rather the total 55 reporting that type of odor. Number in the parentheses after types of treatments represent the total number of plants that tried a specific treatment to combat one or more causes of odor.

are given in Table 13 .

7.1. Aeration

The term "aeration", is ordinarily used in connection with mechanical devices or procedures which are designed to increase the area of contact between water and air. Not until the last half of the 19th century did aeration become a marked feature of municipal water supplies. Even then the number of applications were small and pertained chiefly to stored waters subject to taste and odors from algae growth. In this period, aeration was also applied here and there generally to ground waters for removal of iron and manganese and also to eliminate malodorous gases from sulphur bearing ground waters.

Aeration helps in removing solids like algae, Iron and manganese, liquids like volatile oils (essential oils of algae) and scents and gases like carbon dioxide hydrogen sulphide, methane and sulphur dioxide and hence improves taste and odor in water. Natural waters are so deficient in Oxygen as to effect the taste are found in the lower layers of lakes and reservoirs in late summer and late winter seasons (Art. 5.6.), in deep wells and in the dry weather flow of some sluggish rivers. Aeration will improve the taste by supplying the deficiency of oxygen, will reduce the free carbon dioxide,

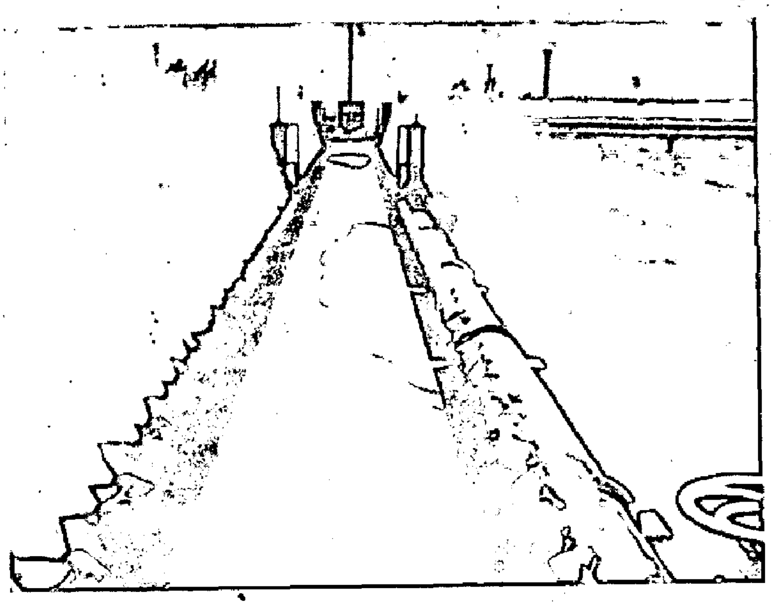


Fig. **Spray Aerators**

The installation shown is at West Palm Beach, Fla. Spray aerators require such a large area that they cannot be housed economically, and they generally are not used during freezing weather.

Figure. 8.

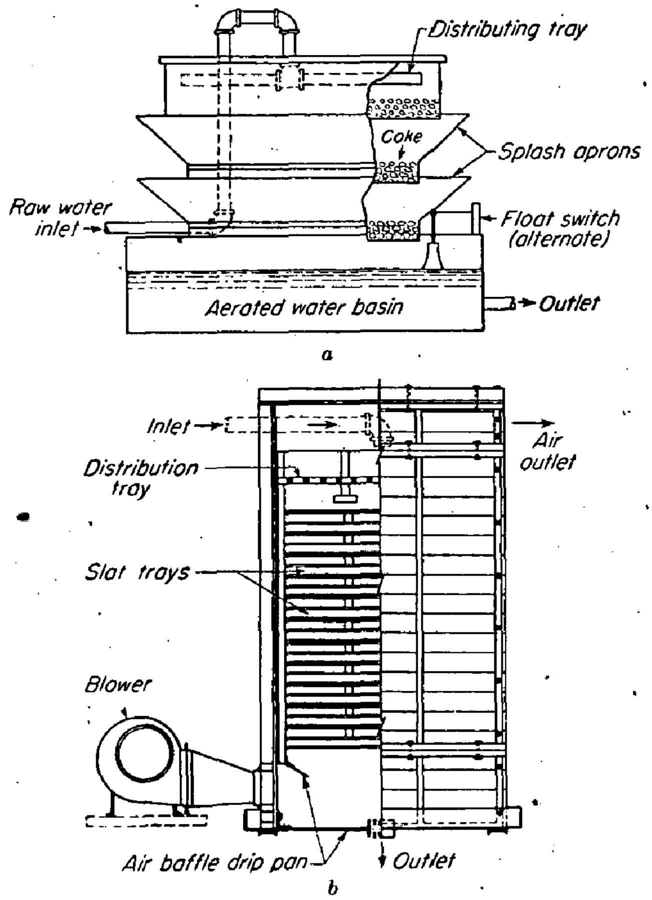


FIG. Aerators. (*a*) Coke-tray aerator. (*Courtesy of the Permutit Co.*) (*b* Infilco forced-draft aerator. (*Courtesy of Infilco.*)

Figure. 9.

and will largely remove any hydrogen sulphide present. Hydrogen sulphide cannot always be removed by aeration alone (6,3., p 536). Scrubbed flue gases containing carbon dioxide are first diffused through the water containing the hydrogen sulphide. The dissolved carbon dioxide lowers the pH, thus releasing the hydrogen sulphide. Excess carbon dioxide is thereafter removed by aeration.

It is estimated that half of all aeration installations in U.S.A. were made for the removal of tastes and odors. The inventory of water treatment plants prepared by the U.S. Public Health Service in 1948 lists 1, 574 plants having aerators (9). This is the breakdown as to type :

Cascade	462
Trays	365
Spray	182
Patented types	118
Combinations	52
Unspecified	395

Aerators in use today are many and varied. They usually consists of water falls, air diffusion units or spray nozzles. Various types of aerators are shown in figs.8,9,10. Water may also be aerated by simple

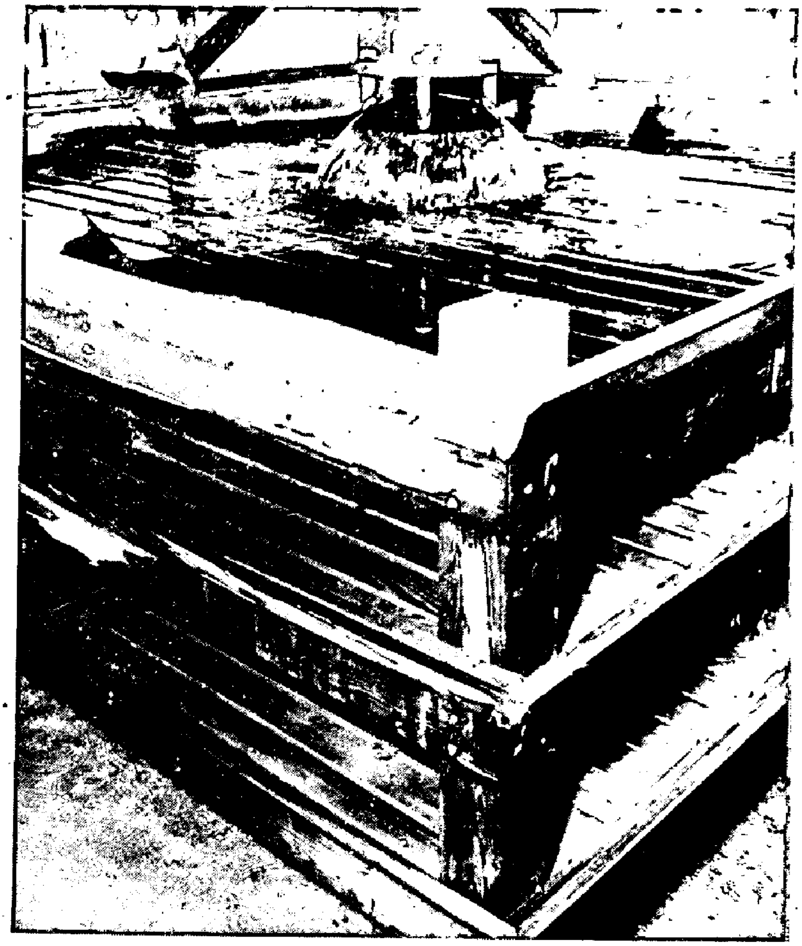


Fig. Multiple-Tray Aerator

This slat-bottomed unit—in use in Duval County, Fla.—produces good turbulence and exposes a large water surface area to the atmosphere. The illustration is taken from a paper by S. W. Wells (8).

Figure. 10.

exposure to air, as in aquoducts, basins and reservoirs. When an airlift pump is used to pump a deep well, the water is generally sufficient aerated so that further exposure is not necessary. High pressure aerators, with a water pressure of 110 psi. at the Spray nozzles, have been installed for odor removal at two Virginia Plants (40-41).

In reducing tastes and odors due to micro-organisms, filteration is generally more effective than aeration alone, but aeration will aid other corrective measures. Sometimes the overall cost of the installation and operation of an aerator at a water purification ~~and~~ plant is higher than the cost of treatment by activated carbon or of other corrective measures, particularly where the necessity for treatment is seasonal where the taste and odor problem is serious, however, the combined cost of aeration plus other types of treatment is often much less than that of such treatment without aeration. This is particularly true where intensive aeration by means of high-pressure nozzles or difusion type aerators of large capacity are used. Data on these types of aeration are limited. More attention should also be given to the use of aeration after filteration, particularly by air diffusion.

Aeration reduces odor concentration by 10 to 20% unless they are extremely volatile such as hydrogen sulphide and sewage type odors.

7.2. COAGULATION

Coagulation is an important phase of corrective treatment, largely because it is vital step in the overall efficiency of any filteration plant. Good coagulation and sedimentation are of material aid to all other corrective measures that may be used in connection with taste and odor treatment. To be of maximum value, these and all other measures should be carefully integrated, because it is well established that, with in the range of reasonable economy, no one type of treatment is the answer to all taste and odor problems.

7.2.1. Coagulation and Algae

Addition of Co-agulant frequently makes filteration difficult, as the natural buoyancy of the algal cells prevents rapid sedimentation of the floc and the filter load is increased. Many plants reported that continued use of coagulant was practically impossible. Baylis and Gerstein (64) consider that certain algae add toughness to the flocculated particles deposited on the filter and thus tend to form a tenacious and impermeable mat on sand surface of filter. Increasing the coagulant dose sometimes helps to overwhelm the buoyant effects of the algae with an enormous amount of floc. This method is very expensive. It is not unusual to find that increasing the co-agulant dose does little to improve filteration. Activated carbon when added before or with the co-agulant, is effective in producing a more settable floc, as has been demonstrated at Chicago (64). Addition of clay to produce artificial turbidity aids in more denser floc and easily settable. Baylis (65) has offered the useful suggestion that in water like the great Lakes, which are saturated with calcium bicarbonate, the addition of a small quantity of lime would cause precipitation of an additionl amount of calcium carbonate and economically provide a heavy material to weight the floc. Prechlorination appears to be most effective method of aiding co-agulation in presence of algae particularly when the organisms are susceptible to disintegration by the Chlorine.

7.3. Activated Carbon Treatment

One of the means most widely used for taste and odor control is treatment with activated carbon, a product which has been used in more than 1,200 water purification plants in the United States and Canada.

The first recorded use of powdered activated carbon in water purification was by two Chicago meat packing plants in 1927. The first practical application in a municipal supply was conducted in 1930 by George R. Spaulding of the New Milford, N.J., plant of the Hackensack water Co. U.S.A.(31). The wide scale adoption of activated carbon since 1930 amply testified to its efficiency as a means of controlling tastes and odors in water supplies. This treatment has outstanding advantage over chemical methods. Ease and flexibility, coupled with practically universal effectiveness and low cost, are important factors leading to the adoption of activated carbon as a means of providing palatable water (39). It is not necessary to determine the exact cause and source of the offending material before treatment can be prescribed, where as other methods may be applicable only to a limited class of substances. Carbon is simply and easy to apply. Although dosages of 2-5 ppm are usually effective, enormously greater amounts can be applied without danger of causing serious harm. And by no means the least of its advantage is the fact that its use appears to meet with the water consumer's approval, which is seldom accorded to other chemicals.

7.3.1. Properties of Activated Carbon

Many raw materials and processes may be employed in the manufacture of activated carbon and the product itself is widely used in industrial fields. The quality adopted for water supply treatment is usually produced from an inexpansive raw material such as wood. The raw material is charred at a temperature below 500°C. This char is then activated by slow burning, under very closely controlled conditions, at temperatures above 800° C. Close adherehce to minutest details of manufacture is necessary to assure production of uniform quality (42, 43).

Activation of carbon gives the carbon surface ability to attract and hold odorous substances which may be present in water supply. This phenomenon of concentrating certain substances at exposed surfaces is called adsorption. Although many materials possess adsorptive properties, activated carbon is the most notable, because it is applicable to so many different uses. The various compounds present in water will be adsorbed in inverse ratio to the solubility of the compounds. Thus, since odorous-compounds in water are usually organic compounds which are only slightly soluble, they are easily adsorbed. Adsorption by carbon is low at higher pH values of water.

The adsorptive capacity of different activated carbons for pure phenol, called their "phenol value" offers a basis for their general comparison. However, the phenol value does not necessarily reflect their relative efficiency in removing specific odors and tastes. The phenol value is defined as the mg/l(ppm) of activated carbon required to reduce 100mg/l (0.1 ppm) of phenol by 90% i.e. to 0.01 ppm value. In making the test, pure phenol is dissolved in specially prepared distilled water.

Baylis (66) suggests that the phenol- absorption requirement of a satisfactory carbon be limited to 35 ppm. Activated carbons having a phenol value in excess of 30 are not generally regarded as acceptable for use in water treatment. Thus, most commercial carbon-s used in water treatment possess a phenol value between 15 and 30. In this respect it may be pointed out that there is considerable disagreement among individuals using or supplying activated carbon, regarding the value of phenol test for determining the ability of carbon to remove tastes and odors from water. It has, however, been tentatively adopted (42, p 1154), and will in all probability continue to be used until a better test, upon which all will agree, is developed.

Other tests proposed toward the physical measurment of odor - removing ability of activated carbon are (1) the dilute-iodine test, and (2) the threshold-odor test. In the iodine test a known weight of the carbon is shaken for a predetermined time with a solution containing a known weight of iodine. The iodine absorbed is a measure of the odor - absorbing power of the carbon. The test has the advantage of being simple, but it may indicate even less than the phenol test with respect to the quality of the carbon. The threshold-odor (66) test is difficult to make but it has advantage that it may measure directly the characteristic most desired in the activated carbon under absevation.

Granular activated carbon is generally a millimeter or less in diameter; powdered activated is normally ground to such size that 50% will pass a 300 mesh sieve and 95% a 200 mesh sieve (A.S.T.M.). The adsorption capacity of finely divided activated carbon can be understood when it is realised that 1 cu.ft. of this substance is estimated to present a surface of about 3,000,000 sq.ft. to the water in which it is suspended. It can be expected, in general, that good activated carbon will weight 10 to 11 lbs. per cu.ft. The cost of treatment, in 1950, ranged between 40 cents and $ 1 per million gallons in U.S.A.

7.3.2. Points of Application of Activated Carbon

In water purification practice, activated carbon has been applied to raw water, to the mixing chamber, to the settling basin and to the filter influent. Generally speaking, however, thepoints of application can be grouped in two categories; prior to coagulation, and after coagulation.

According to data obtained from Several field surveys, carbon is usually added prior to coagulation. This point of application has many advantages in it; (a) permits the use of high carbon dosages without adversely affecting the filter runs; (b) aids in the stabilization of sludge in the settling basins; and (c) acts as a buffer for any sudden surge of odors in the raw water supply.

Application of carbon to the filters is, on the other hand, frequently claimed to be the most economical point of treatment for odor control, although if extremely high dosages are required, the filter runs will be adversely affected. Passage of any appreciated quantity of carbon through the filters must, of course, be be avoided. The presence of carbon in effluent from filter can be detected by appearance of a black deposit on glass wool on passing effluent through a glass wool filter plug. In general, experience has shown that feeds of from 80 to 100 lb. per mil. gal. (9.6-12.0 ppm) can be applied for short periods, and that feeds up to 40 lb. per mil. gal. (4.8 ppm) can be applied continuously just ahead of the filters without appreciably affecting the filter runs. When higher doses are required the feed is split, part being applied continuously along with or ahead of the coagulant and the remainder just ahead of filters. Pretreatment chemicals and processes may accomplish some reduction of odor, but perhaps the greatest advantage of pretreatment chemicals is that they remove organic matters, suspended solids, etc. Thus, the water as it reaches the filters contains less of those impurities which might hinder the adsorption of odors by the activated carbon applied to the filters.

The use of other chemicals also influence the point of carbon application and the amount of carbon required. If pH adjustment is practiced, the carbon should be added 15- 20 minutes before the addition of lime or soda ash. Activated carbon should never be added with chlorine at the same point as the carbon will adsorb some of the chlorine and reduce its disinfecting power. These chemicals should at least be added 15 minutes apart in the treatment works. Which one should be added first depends upon the local situation and condition of water being treated, but generally the carbon should be added at first since it will remove odors which may be emphasized by chlorination i.e. phenolic odors. In the absence of chlorine intensified odorous compounds, application of chlorine first is advantageous; chlorine will have its full disinfection power being unadsorbed by carbon and carbon will remove the chlorinous tastes produced by excess chlorine. Also, chlorine will have cumulative odor removal effect by oxidising certain odorous compounds.

At times the odor in the raw water has increased so rapidly that it has passed through the water purification plant unnoticed. Under such circumstances it is best to apply carbon immediately on the top of filters in order to accomplish odor removal on the water nearest to consumer. If treatment for odor removal is normally made on the raw water as it enters the plant, there would ~~an~~otherwise be several hours additional delay before the properly treated water reached the distribution system because of the time it takes for the water to pass through the mixing and settling basins. The application of carbon on top of the filters can either be discontinued or reduced when the treated and deoderized raw water has passed through the basin, depending principally upon the intensity of the odor in the water being treated. It is a common practice at certain water treatment plants to add small doses of activated carbon regularly to raw water in order to keep low the intensity of taste and odor problems.

Where sand filteration is not part of purification process, carbon may be applied to reservoirs for controlling odor conditions. Carbon should be applied as a slurry to the surface uniformly. If a reservoir can be taken out of service for a period of 48 hours or longer, the most practical way of treatment will be application of sufficient carbon in a single dose to render the water palatable. If a service cannot be interrupted, however, the carbon should be applied at a dose of 1.2 ppm., avoiding any application within 20 to 30 ft. of the gate well. By following this practice, very little carbon will get into the distribution system, and application can be repeated at weekly intervals until a sufficient dosage has been applied to produce a palatable water.

Activated carbon can be fed both dry or suspended in water as slurry. To-day, special equipment for both dry and suspension (slurry) feeding is available. Equipment selected should have sufficient capacity to handle high carbon dosages to meet emergencies. Feed lines from the equipment to the point of application may get clogged due to deposition of carbon particles. The use of rubber hose is advantageous since any ~~a~~ clogging of lines can be broken by tapping where flow is restricted. The strength of slurry, where slurry is used should be about 4 percent.

7.3.4. Determination of Optimum Dosage of Activated Carbon.

Laboratory tests for determining optimum dosage are usually conducted on samples of about five gallons of water collected from a point where ~~t~~ treatment would be practical or, if it is already being applied, from a point ahead of application. Fresh samples daily are always preferable, and become essential when the character or intensity of odor changes on standing. All equipment used in the test, including the sample container, should be absolutely clean and should be rinsed into odor free water before use.

The efficiency of carbon adsorption is influenced by other chemicals used for water purification. Among these other chemicals, chlorine has the most predominating influence because of its chemical reactivity with odorous compounds, which frequently alters their intensity as well as their adsorbability. Such influences should be considered in establishing the order in which carbon and chlorine are applied. A through study of these factors can best be made if the sample is taken from the raw water and tests include all the various possible combinations and order of treatment.

In making dosage tests, one-litre samples of the water to be tested should be placed in containers of such size and shape that they can be used in a laboratory stirring machine. No more than five samples should be tested at one time including a sample of untreated water to act as a control or blank. Containers should be placed in the stirring machine and the stirring mechanism started at a rate of about 100 rpm. Four of the five samples of water should then be treated with incremental dosages of carbon. This is best accomplished by using a stock carbon solution prepared by mixing exactly 1.0 gm. of carbon in 1,000 ml. of odor free water, making the addition of 1 ml.

of this stock suspension to 1 litre of water equivalent to a dose of 1.ppm. Carbon dosages selected for the test will depend upon the concentration of odor in the water and the ease with which it is removed by carbon. Table 14. may be used as a basis for starting the work. Then, after the proper carbon dosages have been applied, the samples should be stirred for a period of time equivalent to the detention period in the plant.

Table 14.

Determination of Proper Carbon Dosage for Different Odor Concentration.

Threshold odor of untreated sample.	Carbon dosage - ppm				
	Container ref; 1	Container 2	Container 3	Container 4	Container 5
10 to 20	None	2	4	8	16
20 to 40	None	4	8	16	32
40 to 80	None	8	16	32	64
Over 80	None	10	20	40	80

Record should be made of the exact time selected and that period should be maintained uniformly in all succeding tests. Following the stirring period, samples should be removed from the stirring machine and filtered through a Buechner type funnel containing about a half inch depth of, well washed with odor free water, glass wool. First 200 ml. of a effluent through funnel is discarded and the remainder is used for running threshold odor test as described in standard method (38, p 202) using all precautions. (Art 4.3.1.).

Determination of phenol value and of dosage of powdered activated carbon required to reduce odors and tastes to desire threshold values is based upon the relationships expressed by the Freundlich adsorption isother (44, P 497) . If C_o is the concentration of odor or phenol in the water to be treated and C is the residual concentration produced by the addition of 'm' units of activated carbon, the equilibrium equation states that

$$\log \frac{C_o - C}{m} = \log K + \frac{1}{n} \log C$$

Hence the values of K and 1/n can be read respectively as the intercept at C = 1 and as slope of the straight line of best fit on double logarithmic paper. The co-efficient K is a measure of the fundamental effectiveness of the adsorbent; the co-efficient 'n' is a measure of the change in rate of effectiveness with relative dosage. It follows from the above equation that phenol value includes both the co-efficient K and co-efficient n. specifically, it is expressed as

$$\log m = 1.9542 - (\log K + \frac{1}{n})$$

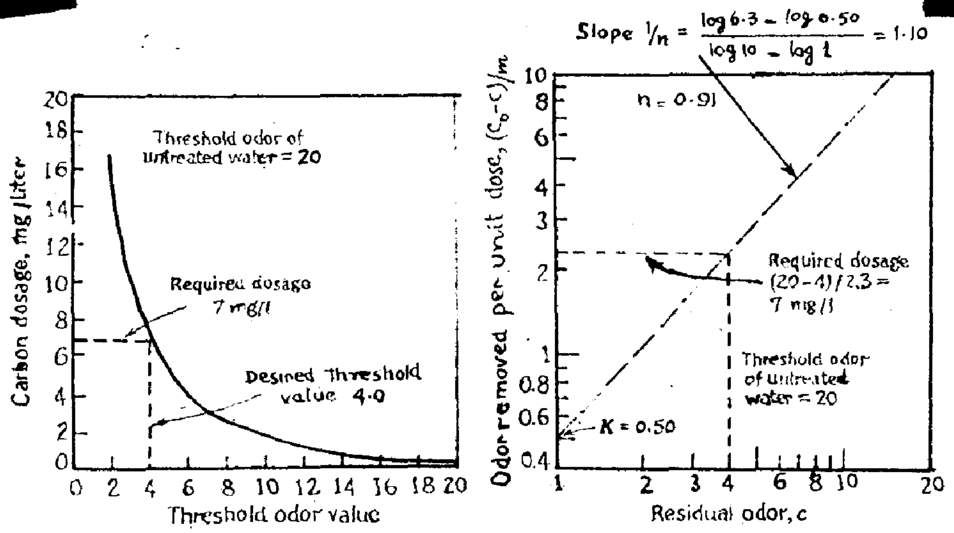


Figure 11 Determination of carbon dosage for taste control (a) Arithmetic plotting of experimental results (b) Double-logarithmic plotting of experimental results.

Figure.11.

because $C_o - C = 90$ and $C = 10$ (By defination of phenol value).

After odors have been determined in filterate either an arithemetic or a double logarithmic plot can be used in accordance with Freudlich equation (explained above)to represent the results. In an arithmetic plot, carbon dosage in mg/l is made the ordinate and threshold odor or taste values the abscissa (see fig11a) In such a plot, the experimental points should straddle the desired threshold value. It is not good to extrapolat beyond actual results on arthmetic plots. Satisfactory extrapolation is possible by double logrithmic plotting of $(C_o - C)/m$ against C (see fig. 11b.) . For the data plotted in figure 11. the dosage of activated carbon required to reduce the threshold odor value from 20 to 40 is 7 mg/ l. Results obtained at one time are not necessarily comparable with those obtained later, due to varying sensitivity of the operator.

If a complete study is to be made, jar tests should be run using various carbon dosages in combination with other chemical treatments used. Only one variable, however, should be altered in each series of tests and, where practicable, laboratory tests should parallel plant practice.

In as much as better treatment results are obtainable in the plant than in laboratory tests, the dosage first adopted for plant scale application, should be about half that indicated by the laboratory tests. If carbon has not been used in the plant for some time, and the plant is therefore not seeded with carbon, however, it is recommended that the full dosage developed in the threshold odor tests be employed in actual plant operation. This dosage can then be gradually reduced by trial and error methods until the optimum dosage is established.

7.3.4. Activated Carbon Dosages.

The quantity of carbon necessary to produce palatable water will vary, depending upon the concentration of the odor producing substances and the ease with which such substances are adsorbed. Carbon dosages employed in actual practice have been as low as two pounds and as high as a thousand pounds per millian gallons of water. When the odor or taste is due to microscopic organisims and is of such intensity as to be readily detected by the average consumers, doses of less than 10 lb. per mil. gal. (2.4 ppm) will seldom be found sufficient to produce a palatable water.

For most economical results, the optimum carbon dosage should be determined at regular intervals by the utilization of the threshold odor test. In some water plants it has been found that 1 ppm of carbon should be added for each threshold odor unit to be removed. In others, where odors are less intense or more readily removed, much lower proportions of carbon are necessary. In one notable case, for example, only 1 ppm of carbon was necessary to remove each 24 threshold odor units. Activated carbon dosage at Hammend City plant Ind., average 100 ppm with a maximum of125 ppm.

For determining most economical dosage of carbons it is desirable to utilize laboratory facilities, remembering, however, the admonition that in plant application only half the dosage indicated by laboratory tests may be required. In absence of laboratory facilities, carbon dosage can be determined by actual plant operation by trial and error to deliver palatable water.

7.3.5. Granular Carbon Filters

The use of carbon as a filter medium in water purification was conceived many years ago. As early as 1883, 22 water plants in U.S.A. were employing charcoal filters due to low absorptive capacity of charcoal these filters were abandoned till the development of activation process when grannular carbon was again used.

Granular activated carbon is now used quite extensively by the bottling industry and in food and industrial plants where palatability is of prime importance. In such applications the carbon is usually installed in pressure type filters supported on layers of gravel. In treatment of public watersupplies, grannular activated carbon filter should never be employed as a replacement for sand. Carbon pores become clogged, and therefore in-effective for removing odorous compounds, where granular activated carbon is to be used unless the water turbidity is exceptionally low, water should first pass through the sand filters.

There have been relatively few municipal installations of granular carbon filter because of economical solution achieved by powdered carbon. A few plants have, however, employed granular carbon in pressure filters as well as in conventional rapid sand type filters. These include installation at Bay City (45) and Frankenmuth, Mich., and at Neenah and Oshkosh, Wis., U.S.A. Where such installations have been made, they have been justified by severe taste and odor conditions in the water supply, and most of these plants employ the granular carbon for removing the last traces of odor, as well as for insurance against heavy surges of odors not suitably controlled by the prevailing dosage of powdered carbon.

7.4. Chlorination

Chlorine is used as both a preventive and a corrective agent in the control of tastes and odors. As previously indicated, sometimes it actually intensified odors already present or produces odors in an otherwise odor-free water. Improved chlorination practices based on new developments in controlling its applications are, however, now available. And where such practices are applied not only is intensification of tastes and odors less frequent but often previously intensified tastes and odors are actually decreased.

Chlorination as a corrective treatment for tastes and odors is most effective when free available chlorine residuals are produced and maintained. Free available chlorine oxidises the odorous compounds to less objectionable forms. Neither algae nor bacteria with the exception of few very resistant species are able to exist in the presence of free available chlorine. Thus, in addition to benifits gained by oxidation, chlorine can be used either to kill or prevent the growth of these micro-organisms, both of which have previously been shown as potential sources of tastes & odors.

Tastes may be avoided by various types of applications of chlorine than is required for sterilization alone, called "Superchlorination", by superchlorination followed by aeration; by superchlorination; a long period of contact, followed by dechlorination; by chlorination before and after filteration, called "double chlorination"; by chlorination preceding filteration; by chlorination after filteration; by use of ammonia in conjuction with prechlorination or double chlorination; by lowering the pH of the water to assure a more rapid dissipation of the residual chlorine; by passing the water after chlorination through a filter of activated carbon; or by various combinations of these methods.

7.4.1. Prechlorination and Double Chlorination

Prechlorination is the application of chlorine preceding filteration in such an amount that no chlorine will pass through the filter. Among the advantages claimed for prechlorination include (1) increased filter runs (2) control of growths in basins and filters (3) deferred putrefaction of settling basin sludge and (4) destruction of hydrogen sulphide and other oxidizable tastes and odors.

The application of chlorine at two points in treatment process is also advantageous under some condition this process is called double chlorination. Among the advantqges of double chlorination are long contact periods with overdoses of chlorine; algae and slimes are avoided, coagulation is aided and tastes and odors are removed very much.

7.4.2. Chlorine Ammonia Treatment.

It has a definite merit as an aid towards the delivery of palatable water. This treatment will not remove taste but is intended to prevent taste incidental to free chlorine i.e. chlorinous. Absence of free available chlorine supresses chlorophenol tastes also. The ratio of ammonia to chlorine doses used is generally 1 to 3. But, it may be necessary to use relatively higher doses of ammonia when phenolic tastes are being controlled, and occasionally an ammonia dose equal to , or more than the chlorine dose may be required. Such high ammonia doses, however, would materially reduce the effectiveness of disinfection, so taste control by free residual chlorination is advocated. This treatment sometimes seems to accelerate algae growths which may intensify odor problems.

7.4.3. Free Residual Chlorination

Free Chlorination consists of the application of chlorine in doses higher than those usually needed for disinfection purposes to secure chemical oxidation. This method may be called as superchlorination also.

It may or may not be followed by dechlorination according to local conditions.

The destruction of phenolic compounds, and other industrial wastes causing tastes and odors in water supplies, by heavy doses of chlorine was discovered in London, England in 1920 and adopted on a plant scale by Norman J. Howard at Toronto, Ont., Canada in 1926(49).

This method of taste and odor control was not widely adopted untill recently, apparently because of the success of treatment with activated carbon or chlorine and ammonia and because of the reluctance of many operators to use high chlorine doses. Like other treatment procedures, free residual chlorination is not a "Cure-all" nor are satisfactory results always secured.

The usual disinfecting dose of chlorine results in the formation of chlorinous products which may have a definite taste and odor. Phenolic impurties in water are the main cause of odor producing compounds after chlorination. Ingols and Ridenour (47) demonstrated that by addition of heavy doses of chlorine to phenol, maximum taste developes when the weight ratio of chlorine to phenol is 2 : 1 and that subsequently this taste diminishes untill at 7 : 1 it has entirely disappeared. It is of interest to examine one of the

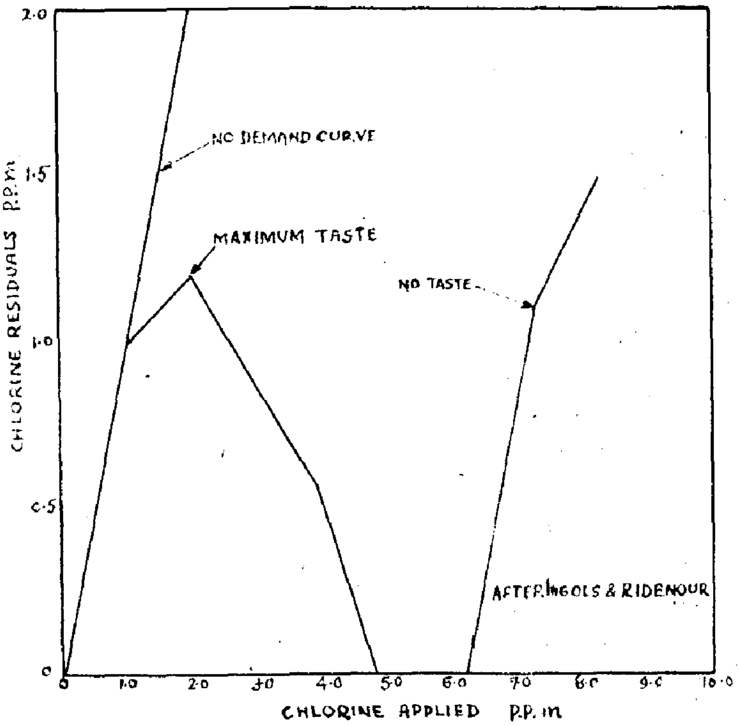


Fig. 12 Effects of Chlorine on a 1 p.p.m. Phenol solution after 24 hours contact

Figure. 12.

graphs prepared by these workers, Fig 12 which shows that between chlorine/phenol weight ratio of 4.8 to 6.2 the chlorine residual disappears, a clear pointer that in certain cases, at least, no dechlorination would be needed. The above are only laboratory studies on pure solutions may not be exactly reproducible in practical treatment.

Further it was deduced from this work that chlor-phenol taste is caused by a quinone - like substance, possible dichloriquinone formed by oxidation of phenol and that heavy chlorination probably resulted in rupture of benzene ring and formation of maleic acid.

The possibility of the formation of Nitrogen trichloride (NCl_3) with resultant tastes and odors and ineffective disinfection is a hinderance to free residual chlorination. It will occur if the pH of the water is 4.4. or less andin alkaline waters high in nitrogenous matter. Nitrogen trichloride can be removed by dechlorination with sulphur dioxide followed by the application of the chlorine - ammonia treatment.

7.4.4 Points of Chlorine Application.

In a purification plant these are a number of points at which chlorine may be effectively applied for taste and odor control, coincidental with disinfection. The usual point of application is in the mixing basin along with other chemicals. Application at this point makes possible the maintenance of free available chlorine residuals throughout the treatment process and into the distribution system. Such a procedure prevents the growth, within the basin and filters, of algae and bacteria that may be responsible for a great variety of tastes and odors.

Maintenance of free available chlorine through out the distribution system is desirable to avoid complaints of tastes and odor originating in distribution system. Such treatment may require such large dosages that residuals near the plant will be unreasonably high. This difficulty is overcome by rechlorination - the application of chlorine at second point, with in the distribution system. Rechlorination is usually effective in long transmission mains, but is not always so when used to control growths in open reservoirs or tanks. For treatment of such units, it is advisable to apply the chlorine as near as possible to the tank or reservoir inlet to achieve good results. Results of chlorination in removing tastes and odors, of summer stratified reservoirs, Encino & Lower Hollywood at Los-angles (50) are very encouraging and more success is anticipated in future. Bleaching effect of chlorine is an additional advantage and produces more attractive water.

7.4.5. Quantities of Chlorine Required.

Chlorine required cannot be stated precisely due to wide variations in chlorine consumption of individual waters. The chlorine requirements of raw water may range from 1 ppm to 35 ppm or even higher chlorine concentration up to 150ppm was build to achieve good result in troublesome zones of Lower Hollywood reservoir. The chlorine demand of finished water is usually low, so that where chlorination after filteration is practiced, chlorine consumption is at a minimum. The usual range is 0.5 to 5.0 ppm., with an average seldom exceeding 1.0 ppm.

Studies, made under S.J. compbell, chief chemist of Torresdale laboratory (57) showed that concentration of 8 ppb was removed by a dosage of 7.5 ppm of Cl_2 and 100 ppm was destroyed by about 75 ppm chlorine at a cost of $ 32.19 per million gallons.

7.4.6. Chlorine Dioxide (ClO_2)

Chlorine dioxide, a strong oxidising agent may be applied to water for the specific purpose of odor and taste control. The use of chlorine dioxide for the aforesaid purpose has been under development since 1944 (50-55). At ordinary temperatures and pressures, chlorine dioxide is a yellow-to-red, unpleasant smelling, irritating gas which is unstable.

In Water works field, chlorine dioxide is produced as needed from sodium chlorite ($NaClO_2$) by allowing a solution of this solid to react with a strong chlorine solution (7,500 mg/l of Cl_2 or a pH of 3.5), or more rarely with an acidified solution of calcium or sodium hyprochlorite.

$$2\ NaClO_2 + Cl_2 \longrightarrow 2\ ClO_2 + 2\ NaCl$$

As applied in water supply plants, the installations employ gas chlorinators to supply the stream of chlorine water. The discharge line of chlorinator is connected to one end of a reaction chamber, and a solution of sodium chlorite is fed, by means of a metering pump into the chamber. The purpose of the chamber is to insure complete mixing of chlorine with chlorite and to complete reaction to chlorine dioxide before it is discharged into the water supply. The theoretical ratio of chlorine to sodium chlorite is 1 to 2.6, but a ratio between 1 to 2 and 1 to 1 is employed in practice with commercial sodium chlorite (82% $NaClO_2$) ClO_2 studies by S. J. Campbell (57) have shown that 100 ppb phenol was destroyed by 0.07 ppm of ClO_2, which was commercial (70%) sodium chlorite and chlorine in a 1 : 1 ratio would require 1 lb each of sodium chlorite and chlorine at a cost of 65 cents per mil. gal. Common dosages of 2 to 3 lbs per mil. gal., which produce concentrations of chlorine dioxide between 0.2 and 0.3 mg/l are being used.

Although chlorine dioxide is itself a disinfectant; the excess of chlorine normally used in its generation is commonly counted upon to accomplish disinfection. Chlorine dioxide has proved effective in destruction of tastes and odors due to phenolic substances. Table 15 shows quantity of sodium chlorite used relative to level of phenolic odors at Philadephia, U.S.A.

Table 15

Quantities of Chlorine Dioxide for Phenolic Odor Removal.

Year	Monthly average Phenolic odor *	$NaClO_2$ used during year lbs.	Percentage of 1954 $NaClO_2$
1951	15	54,000	33
1952	15	77,000	47
1953	29	93,000	57
1954	55	1,63,000	100
1955	28	1,61,000	99 +

* Product of %age time and average threshold number.

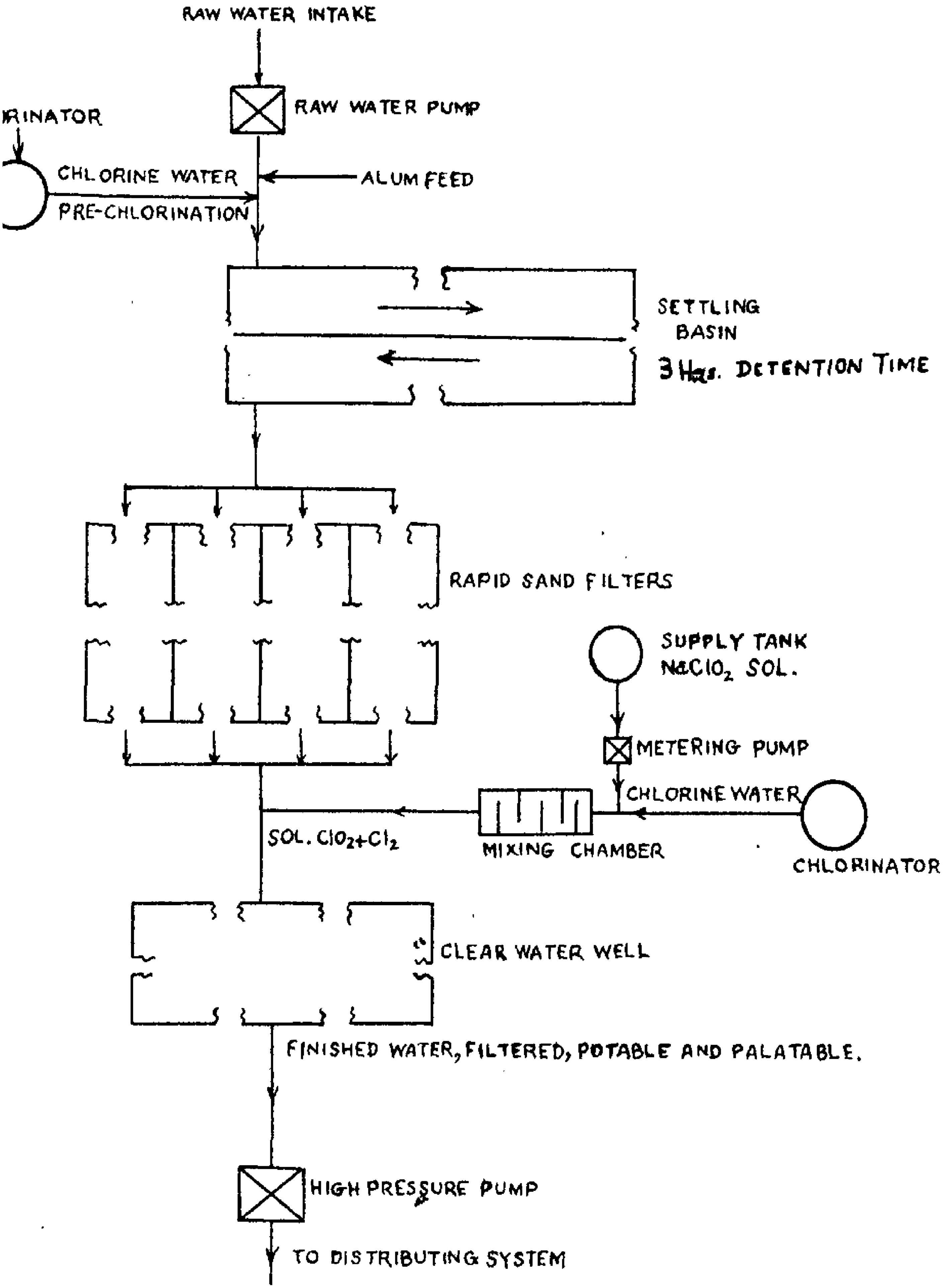
+ 50% of dosage applied in pretreatment.

The full potentialities of chlorine dioxide treatment will be revealed as the process is used to treat more and more supplies under a variety of conditions. At present time, the process has been successful in the control of phenolic tastes and odors in supplies secured from the Niagara River (58) , and in Philadephia (18) water supplies and from a rapidly growing number of other sources. The process has not, however, been effective in eliminating tastes and odors incidental to the presence of paper mill wastes and only partial success has been reported so far in the elimination of taste and odors incidental to algal growth with substantially higher dosages. Chlorine dioxide is the most effective treatment for removing the odors attributed to actinomycetes (65).

Procedure in the use of chlorine dioxide involves chlorination for disinfection followed by the application of chlorine dioxide to destroy tastes and odors. Coagulation or filteration may precede or follow chlorination and precede the application.

7.4.1. Use of Chlorine Dioxide at Niagara Falls Plant.

Experiments undertaken at an auxilary filter



w sheet Showing Chlorine Dioxide Treatment of Water Supplies for Removal of Tastes and Odors

FIG. 75.

plant of the city of Niagara Falls (N.Y.) water department to study the possibilities of chlorine dioxide as a solution to the problems of tastes and odors have demonstrated that chlorine dioxide destroys such tastes and odors as are developed in the water at that plant. This plant supplies 3 to 8 mil. gal. per day, or approximately 10 to 20% of total water supply, has an "onshare" intake which become so polluted, at some times with phenolic compounds and at other times so infected "with algae, that the ordinary methods of treatment often failed to produce a palatable water. This condition is intensified by the fact that phenolic pollution comes in surges rather than at a constant rate, so that water quality varies greatly even from hour to hour.

The treatment as developed at Naigara Falls combines pretreatment with chlorine mainly for disinfection and post-treatment with chlorine dioxide to destroy tastes and odors. The flow diagram for treatment plant is shown in fig. 13. In pretreatment, sufficient chlorine dose is fed to maintain available residuals of 0.4 to 0.5 ppm in settling basin and 0.2 ppm under the filter. 17 ppm of alum with chlorine are also used. Total dose of chlorine used being 1.5 ppm Following 3 hours detention in settling basin chlorine dioxide is introduced at clear well. Chlorine dioxide dosage is maintained at a value of 0.5 to 0.75 ppm available chlorine.

The entire water supply system of the city of Niagara falls is now protected by aforesaid chlorine dioxide treatment, to give year round operations without taste and odor difficulties.

Chlorine dioxide treatment eliminates both difficulties of taste and odors by algae in summer and by phenolic compounds in winter.

7.4.1.1. Cost Saving

Old Method

	Total cost	Cost/mil.gal.
1080 lbs. of Cl_2	$ 157.50	$ 8.73
1800 lbs of carbon	$ 43.10	$ 2.39
New Method		
163 lbs. of Cl_2	$ 43.10	$ 2.39
46.2 lbs. of Chlorite		

Saving of $ 6.34 per mil. gal. or 72.5% of old method cost.

7.4.1.2. Conclusion.

The new treatment permits continuous operation, reduces the amount of chlorine required, eliminates the use of carbon and simplifies operation by making breakpoint measurements unnecessary.

7.5. Ozone

Ozone is another strong chemical oxidant used in water which combine germicidal value with effectiveness in taste and odor control. A few ozonation installations in North Americal have been made primarily for taste and odor reduction. The largest ozonisation plant at Philadelphia, U.S.A., was designed primarily for taste and odor reduction, as, in the limited detention period possible, it was not feasible to control treatment by free residual chlorination. Experience has demonstrated that ozone will completely remove some types of tastes and odors present in water supply. In certain applications involving treatment of water heavily polluted by industrial wastes, it has been found that ozone treatment is effective in reducing odors to a certain extent, but tends to "fix" the remaining odor in such a way that its resists complete elimination. In other instances where ozone does not remove tastes and odors completely, it so changes them in character that this resultant water is attractive to the consumer. This process has proved a failure when odors are due to algae and decaying matter. Difficulty of ozone solution in water due to relatively small partial pressure of ozone in air, and fixing of residual odor in treated water have militated against the exploitation of this otherwise very promising substance. Since the process has not been much used, it

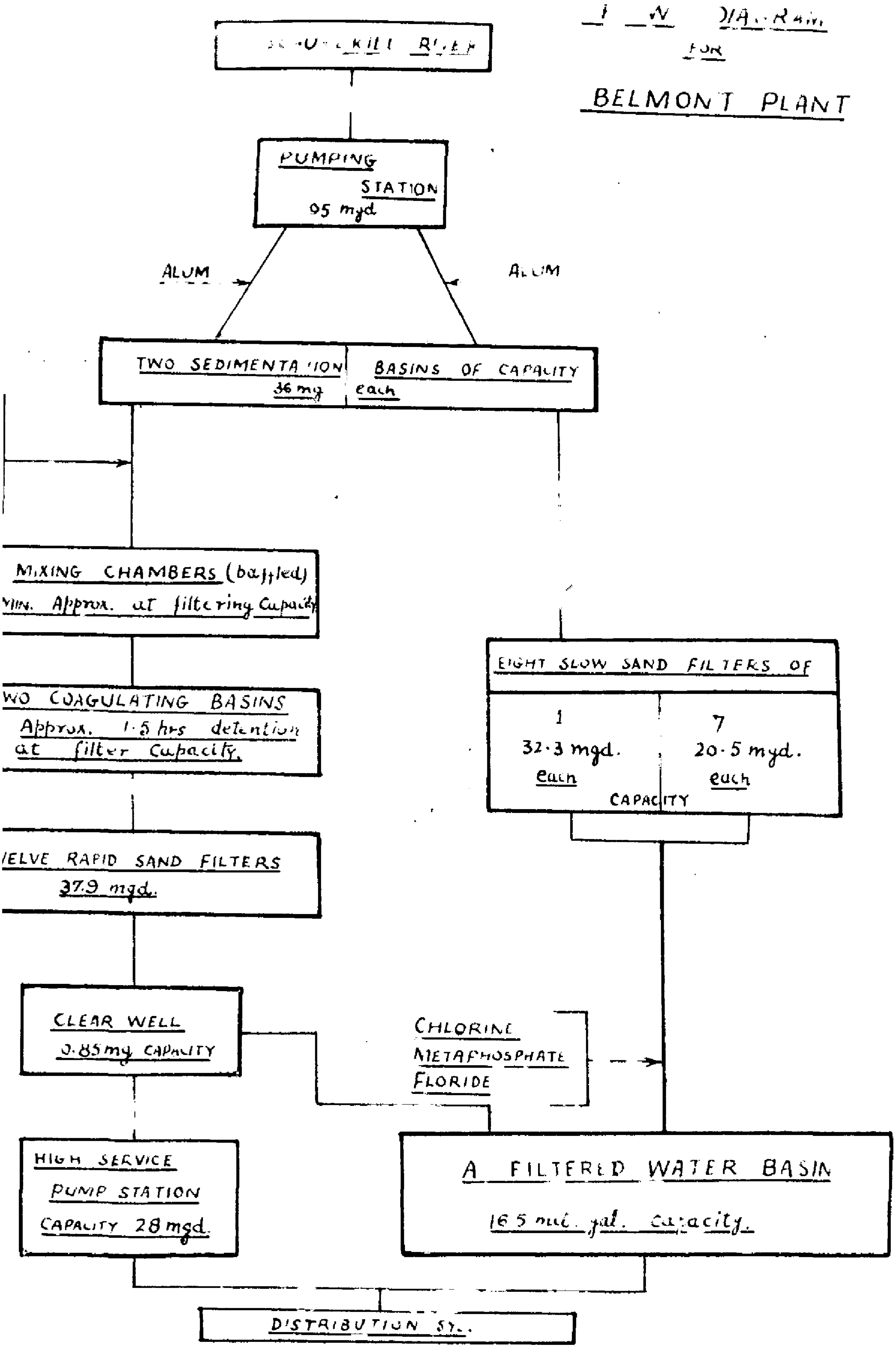
FLOW DIAGRAM
FOR
BELMONT PLANT
SCHUYLKILL RIVER
PUMPING STATION
95 mgd
ALUM
ALUM
TWO SEDIMENTATION BASINS OF CAPACITY
36 mg each
MIXING CHAMBERS (baffled)
MIN. Approx. at filtering Capacity
WO COAGULATING BASINS
Approx. 1.5 hrs detention at filter Capacity.
IELVE RAPID SAND FILTERS
37.9 mgd.
CLEAR WELL
0.85 mg CAPACITY
HIGH SERVICE PUMP STATION
CAPACITY 28 mgd.
EIGHT SLOW SAND FILTERS OF
1
32.3 mgd. each
7
20.5 mgd. each
CAPACITY
CHLORINE
METAPHOSPHATE
FLORIDE
A FILTERED WATER BASIN
16.5 mil. gal. capacity.
DISTRIBUTION SY..

Fig. 14.

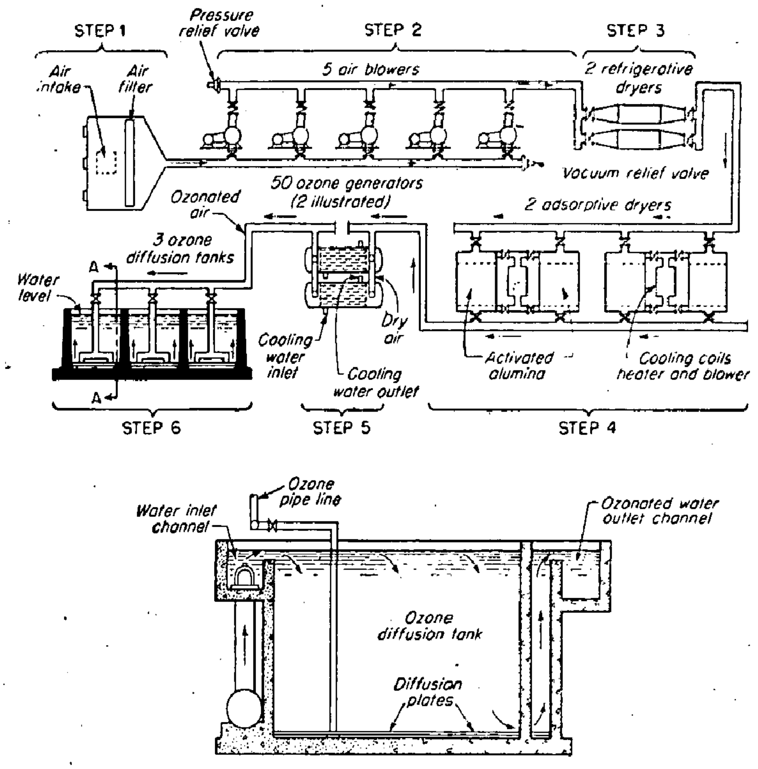


FIG. . Flowing-through diagram of an ozone plant. (*From E. J. Taylor and E. L. Bean, Eng. News-Record, July 28, 1949, p. 32.*)

Figure. 15.

Philadelphia, Pa., is shown in fig 15 . It has been found at this plant at that for each pound of ozone produced, 8 to 9 kwhr are required by the ozone generator plus 2 to 3 kwhr for the operation of auxilary equipment. A medimum capacity of 1. 5 to 3.0 millon cu.ft. of air is required daily to treat 39 mgd. The air is dried , cleaned, and cooled before passing through the electrical lorona where the voltage between electrodes is about 15,000. The ozonated air is introduced through porous plates at the bottom of the diffuser tank. The ~~water~~ air rises through 18 ft. depth of water which is passing downward through the tank with a contact period of better than 10 minutes.

"It was noticed that for 8 months of 1951 with ozonisation functioning, less than 20% of plant effluent samples had cold odors characterised as musty or 'related' In the same months of 1952 with no ozonisation inspite of use of carbon 28% had such odors."

7.5.1.1. Conclusion

Ozone speedily splits many of the organics which are slow to react with free chlorine. When time of contact is a major factor, ozone is definitely an advantage.

7.6. Bleaching Clay

Bleaching clay has been used continuously since 1930 for the removal of taste and odors due to oil refinery wastes in the Delaware River of Chester, Pa. (60) Experiments, notably those by Baylis (27) at Chicago, have not, however, indicated that bleaching clays are of much value for this purpose. The samples tested by Baylis showed an odor adsorption probably less than 1 percent that of a good grade of activated carbon on the particular odors on which the samples were tried. Tests indicated little or no adsorption of phenol. Even though bleaching clay cannot be depended upon to remove objectionable tastes and odors, an appreciable saving in cost and improved plant operation can sometimes be obtained by applying it along with a coagulant and adding activated carbon at the outlet of the settling basin before the water goes to the filters.

7.7. Other Methods.

Potassium permanganate has been found effective in controlling some tastes produced by microscopic organisms. Gibbons (68) found that it removed tastes and odors caused by solvent naptha wastes, rosin, soap and fermenting cereal wastes. It may be used in combination with chlorine, being applied at such a rate that no pink color passes the filter doses between 0.2 and 0.4 ppm have been reported as successful. There is no instance of its use on plant scale.

Iron and Manganese impart taste to water and should be removed when the tastes become distinct. Methods for their removal may be (1) aeration (2) the application of lime, possibly supplemented with chlorine, (3) chlorination alone (4) the use of base exchange substances etc.

8. INDIA AND ITS PROBLEMS

In India application of ameliorative treatments for taste and odor control are conspicuously absent except for the benefits accrising from conventional type treatments such as sedimentation, coagulation, chlorination and filteration. One of the major reasons being our country is financially poor. Fortunately, taste and odor problems are not severe in India. Because, the major quantity of water used for domestic supplies is either from underground sources or from less polluted flowing streams and rivers. Only a few plants get raw water from impounded reservoirs like plants in Bundelkhand area of Uttar Pradesh which may have some taste & odor problem due to algae. Moreover, our folk have become accustomed to some of the more locally met odors and tastes and others have their senses benumbed enough to detect small traces of odor in water due to bad cold and malnutrition — a sordid boon.

In near future demands of water are going to rise based on the pyramidal effect of soaring population and high per capita consumption. Such demands will be enhanced by an expanded usage by industry which is getting top impetus in our country at present moment. Ever increasing standard of living of people, their developing aesthetics and their ability to pay more will demand a more palatable water. On the other hand, more industries mean more wastes extensive stream pollution and deteriorated quality of raw water. More demands mean constructing artificial impounded reservoirs and tapping surface sources poluted with industrial waste and hence taste and odor problems in our water supplies. It will not be mere optimism if we anticipate taste and odor problems in near future.

It would be well in time to enforce strict stream pollution standards and specilised treatment of industrial wastes be started to lessen the impact of taste and odor problems in our water supplies in future.

Regular seasonal pulses of algae may cause serious difficulties in the operation of water purification plants. Although troubles may be unavoidable, they should not be considered insurperable. The battle against algae can be joined at various points. The concentration of algae in the incoming water may be lowered by avoiding unnecessary fertilization of the supply or by interfering with the multiplication of the organisms by physical (aeration & blacking out by carbon etc.) or chemical (chlorination, CuSO treatment etc.) means. Once in the plant, algae can removed by improving the efficiency of Coagulation (Art. 7.3.) fountain type cheap type of aerators, cascade or just a oxidation of volatile oils and removal of objectionable gases from ground water supplies. A small regular

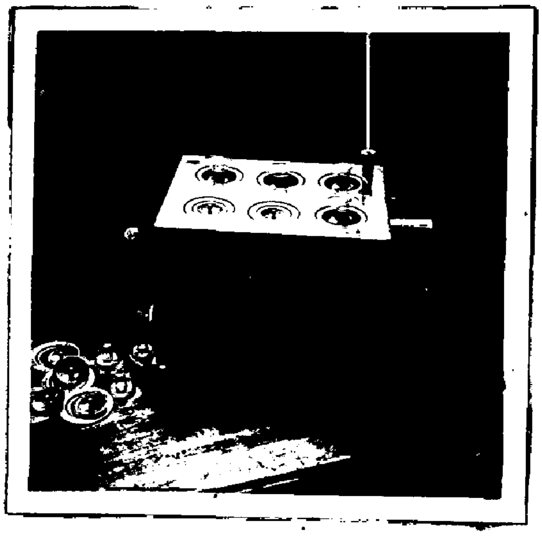


Figure. 16.

dose of activated carbon will be a nice solution to attain palatable water. Carbon can be used to cure all types of odors. For economy dosages of carbon should be actually ascertained in laboratory (7.3.4.) Chlorination should not be used as corrective treatment unless proper controlling equipment is available is available for adjusting doses of chlorine, otherwise intensification of certain odors may take place and worsen the taste and odor problem. Preventative methods (Art 6.) should be more stressed especially in plant. Since very little is known about the taste- amd odor producing substances, the ameliorative treatments are more or less on emperical basis.

The use of threshold odor test should be encouraged and be put as a routine tests carried in the plant. Although, it is not possible to make use of threshold test in all plants due to lack of laboratory facilities and trained personnel. For such cases author suggests a simple and very helpful arrangement as indicated in fig. 16. This is a standard laboratory hot bath provided with an ~~a~~ electric heating unit, thermostat control and thermometer. Wide mouth glass bottles of 750 to 1000 ml. Capacity are half filled with water to be observed and set in the water bath. In addition to the bottles containing the samples under test, a bottle containing odor free water should serve as a blank so that differences can be observed .

more readily. The constant temperature of the bath is maintained at 60° C. The bottle mouths are covered with laboratory watch glasses when samples are placed in the bath. After about 30 minutes in the water bath, the water in the bottles is at 60°C. Observation of odor can now be made by removing bottles from the bath with watch glasses held firmly in place and shaking vigorously. Immediately after shaking, remove the watch glass of the bottle under test and place the rose in the wide mouth and note odor. Similarly, the other samples can be observed. These observation made from day to day will aid the operator in noting the presence of any perceptible odor and its trend. By this procedure odors can often be detected in time to apply a remedy in plant treatment. Perception of any odor will pinch the operator and authorities conscious and they will try to remedy it; otherwise if no threshold test is carried, the odorous water will pass on to consumers giving rise to complaints.

* * *

9. CONCLUSIONS

Although great stride have been made with in U.S.A. in the production of consistently palatable water, many communities are failing in their obligation to consumers.

These have not been developed any adequate standards for testing taste and odor in our public water supplie The elfactory lacks precision. There is no absolute odor value. Different persons react differently to a given concentration of odoriferous substance at different times. Thus water works profession lacks a reproducible method for measuring the intensity of odor.

Algae are the most frequent offenders and cause of odors in water supplies, with decaying vegetation a close second. Trade wastes, although they occur less frequently, can be much more troublesome. Algae types most frequently causing odor problem are (1) Anabaena (2) Apharizomenon, Asterionella, Diatoma, Dinobryon, Synedra, Synura and Tabellaria.

Taste and odor due to dissolved minerals from underground strata constitute no problem except in certain localized areas. In surface waters the predominant problem is odor rather than taste. Chlorinous odors continue to be a serious issue, and return to the use of Cl_2-NH_3 treatment for improvement of water palatability appears to be growing trand.

Greater importance of palatability is demonstrated by the wider adoption of the threshold dilution procedure for odor evaluation.

Preventive measures, except for control of algae with copper sulphate are employed very infrequently . Reports of completely successful correction treatments show activated carbon for ~~mm~~ in the lead with an overall effectiveness of 86% compared with 25% chlorine dioxide 23% for - super and dechlorination, 17% for free residual chlorination and 9% for aeration.

The proper point of carbon application in relation to chlorine and pH adjustment chemicals is deserving of further attention in water treatment practices.

Indeed the day may not be distant when odor-masking or deodorant compounds are added to improve the tastes of water. Certainly a slight peppermint taste would be preferable to that of dilute hydrocarbons and will increase the acceptability of water by consumers.

From the view point of public health and consumer relationship, water palatability has greater significance, and the delivery of a consis tently palatable water at all times should be the goal of all progressive individuals in water works profession.

10. REFERENCES

1. "Control of Odor and Taste in water supplies, " by E.A.Sigworth. Jour., A.W.W.A., 49:12:1507. Dec. 1957.

2. Fischel, Daniel N. "Control of Oil Lines in Water Areas." Jour., A.W.W.A.,38:1285(1946).

3. "Changing Concept of Water Quality." by Jack E.Mokee. Jour., A.W.W.A., p27 1957.

4. Wtr. Wks. Eng. Vol. 112:395 May 1959.

5. Herbert O.Hartung. "Taste and Odor" Jour., A.W.W.A. -p1363 Nov. 1960.

6. Wolman, Abel. "Year of Improvement in Water Supply Quality." Jour., A.W.W.A., 48: 905 (Aug. 1956)

7. Pure Water, 9 : 22(1957) Published by Bureau of Water, Deptt. of Water and Sewers, Chicago Illinois.

8. Porges, Ralph. "Who gets How much of What kind of water- From Where and Whom ?" Wtr.Wks. Eng.110;135 (1957).

9. Water Quality and Treatment - Amanual prepared by the American Water Works Association (155).

10. Ingols and Ridenour, Wtr. & Sew.Wkr., 95:197.1948.

11. Silvery, J.K.& Roach, A.W."Actinomycetes may cause Taste and Odor in Water Supplies." Public Works, 87:5:103 May 1956.

12. "Water Quality Problems in Small Wtr.Wks.System." Carl. B.Jhonstonp929, Jour., A.W.W.A., July 1957.

13. Kent A. Bartholomew."Control of Earthy,Musty Odors in Water by Treatment with Residuals of Copper." Jour.,A.W.W.A., p 481 (1958).

14. Waksman, S.A.The Actinomycetes. Chronica Botanica Co., Waltham Mass. (1950).

15. Ray L. Derby."Chlorination of Deep Reservoirs for Taste and Odor Control. " Jour., A.W.W.A.,p775 July 1956.

16. Rice H. Burttsehell. Aaron A.Rosen, Francis M. Middleton and Morris B. Ettinger"Chlorine Derivatives of Phenol causing Tastes & Odors." Jour., A.W.W.A., p 205 February 1959.

17. Francis M. Middleton, Aaron A. Rosen & Rice H. Burttsehell. "Taste & Odor Research Tools for Water Utilities" p 21 Jour., A.W.W.A., January 1958.

18. Elwood L. Bean "Taste & Odor Control at Philadelphia Jour., A.W.M.A., p 205 (1957).

19. Bean, Elwood L. " Progress in Taste & Odors Elimination, Taste & Odor Control "Jour., A.W.W.A., 14:2:1 Feb(1948).

20. Howard, N.J. "Modern Practice in the Removal of Taste & Odor" Jour., A.W.W.A., 9:766 sep.(1922).

21. Adams, B.A."Substances Producing Tastes in Chlorinated Water"Wtr. & Wtr.Eng. 33:387:109(1931).

22. Ettinger, M.B. & Ruchhoft, C.C.Jour., A.W.W.A., 43: 561 July 1951.

23. Ingols, R.S.&Ridenour, G.M."The Elimination of Phenolic Tastes by Chloro-Oxidation." Wtr.&Sew.Wks. 95:187 (1949).

24. Ruchhoft, C.C. & Ettinger, M.B. "Taste & Odor in Water Resulting from Industrial Wastes." Proc.Ind. Waste Conf.,3rd Conf., External Ser.PurdueUniv. No. 64:32(1947).

25. Soper, F.G. & Smith, G.F. "The Helogenation of Phenols" Jour., Chem. Soc. (London)1582 (1926).

26. De La Mare, P.B.D., Ketley, A.D.: & Vernon,C.A."The Kinetics & Mechanism of Halogen Substitution. Part I Acid-Catalysed Chlorination by Aquous Solns. of Hypochlorous Acids." Jour., Chem. Soc. (London)1290. (1954).

27. Baylis, John R."Elimination of Taste & Odor in Water." McGraw Hill Book Co., New-york(1935).

28. Brans, H.: Middleton, F.M.; and Walton, G."Organic chemical Coumpounds in Raw Water & Filtered sufface Waters."Anal. Chem. 23:1160(1951)

29. Middleton, F.M.; Brans H., ; & Ruchhoft, C.C."Fundamental Studies of Taste & Odor in Water Supplies." Jour., A.W.W.A. 44:538.(1952).

30. Spaulding, Charles H. "Quantitative Determination of Odor in Water. Am. Jour. Pub. Health, 21:1038(193

31. Baylis, John R."Procedure for Making Odor & Taste Determination" Wtr. & Sew., 79:425(1932).

32. Gullans, O."Procedure for Making Odor Determination Jour. A.W.W.A., 25:974(L933).

33. Fair G. & Wella, W."Determination of Odoros in Water." Wtr. Wks. Eng. 87:1051(1934).

34. Helbig, W.A. " A Uniform Basis for Activated Carbon Comparision. " Jour., A.W.W.A., 31:1931(1939).

35. Laughlin, H.F."Developments in Taste & Odor Control' Jour., A.W.W.A., 32:1191(1940).

36. Hurbert, R. & Feben, D. "Studies on the Accuracy of Threshold Odor Values." Jour., A.W.W.A.,33:1945(194

37. Spaulding, Chales H. "Accuracy of & Application of Threshold Odor Tests. Jour. A.W.W.A., 34:877(1942).

38. Standards Methods for Examination of Water, Sewage & Industrial Wastes by APHA." A.W.W.A., FSIWA. New-york (1955).

39. Baylis, John R. "D-evelopment of Activated Carbon in Water Treatment." Jour., Taste & Odor Control 5:1:2(1938).

40. Haynes, Lawson & Grant, Wallace. "Reduction of Chemical Odors at Nitro, West Virginia. Jour. A.WWA 37:1019 (1945).

41. Haynes, Lawson. "Treatment of Industrial Water Pollution at Nitro & Charleston, " W.Va. p309 Jour., A.W.W.A., March 1957.

42. American Wtr. Wks. Association. Specifications & Tests for Powdered Activated Carbon - Subcommittee Report Jour., A.W.W.A., 30: 1133(1938)

43. "Taste & Odor Control in Water Purification." Industrial Chemical Sales Div., West Virginia Pulp & Paper Co., New-york (1942).

44. Gordon M. Fair & John C.Geyer. Water Supply & Waste Water Disposal.

45. Water Supply Control by Charles R. Cox Bureau of Enviornmental Sanitation 1952.

46. Ingols & Ridenour, Water & Sewage Works, 1948,95:18

47. General Psychlogy by Douglas H. Fryer., Edwin R. Henry, Charles P.Sparks.

48. Ray L. Derby. "Chlorination of Deep Reservoirs for Taste & Odor Control " July 1956 p 775.

49. Howard, N.J. "Progress in Superchlorination Treatmen for Taste Prevention at Toronto, Ontario. "Jour., A.W.W.A. 23: 373(1931).

50. Woodward, E.R. "Generating Chlorine Dioxide. Chem. & Eng. News , 22:1092(1944).

51. Synan, John F., MacMahon, J.D.; & Vincent, G.P."Chlorine Dioxide - A Development in Treatment of Potable Water." Wtr. Wks. & Sew., 91:423(1944).

52. Faber, Harry A."ATheory of Taste & Odor Reduction by ClO_2. Jour., A.W.W.A., 39; 691 (1947).

53. Ingols, R.S. & Ridenour, G.M. "Chemical Properties of Chlorine Dioxide in Water, "Jour., A.W.W.A., 40:1207(1948).

54. Aston, Roydon N. "Development in the Chlorine Dioxide

55. Aston, Roydon N. "Chlorine Dioxide Use in Plants in the Niagaria Border. Jour., A.W.W.A., 39: 687(1947)

56. Ringer, Walter & Campbell, Sylvestir J. "Use of Chlorine Dioxide for Algae Control at Philadelphia. Jour., A.W.W.A. 47: 740 (1955).

57. Bartuska, James F. "Ozonisation at Whiting, Ind. Jour., A.W.W.A., 33: 2035(1941).

58. Hann Victer. Ozone Treatment of Water. Jour., AWW A 35: 585(1943).

59. Norcom, George D. "Bleaching Clay in Water purification ." Wtr. Wks. & Sew., 80: 53(1933).

60. Baidler, L.M. " Mechanism of Taste & Odor (Smell). Paper Presented at A.D. Little. Flavour Symposium (Nov. 19, 1956).

61. "Taste Threshold Concentrations of Metals in Drinking Water." Jesse M. Cohen, L.J. Kamphahe, E.K. Harris & Richard L.Woodword. Jour., A.W.W.A., p660 (May 1960).

62. Water Supply Engineering. H.E. Babbit & James J. Doland.

63. Baylis, J.R. & Gerstein, H.H. 'Micro-Organisms in Lake Michigan Water. Munic.New & Wtr.Wks76:291(1929)

64. D.H.Matheson. Wtr. Wks & Sew. 1956. p R1982.

65. J.R. Baylis, Wtr. Wks & Sew. p 217. June 1933.

66. 9E.J.Taylor, Wtr. Wks. & Sew., pl. January 1938.

ERRATA.

1. Chapter. 10.

(a). To get the correct serial No of the referance, increase the existing serial No, from 45 onwards by one i.e. read 45 as 46 &so on.

(b). 45th Reference.

" Use of Granular Activated Cabon at Bay City." Jour., A.W.W.A., 32:593(1940).

(c). Interchange the serial No's of 49 &50 got after applying No (a) correction.