Water Quality Problems in Relation to Seafood Processing in Different Regions of India

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Seafood processing industry requires plentiful supply of potable water. Standards of water applicable to seafood industry in India are Indian Standards IS: 4251 and EEC Directive No. 80/778/EEC. For exporting seafood to European Union the process water should conform to the quality parameters contained in the EEC Directive. Guide level and maximum admissible concentration (MAC) for most of the characteristics are given in the Directive. 259 samples of water from seafood processing establishments located in different regions of India were studied during the three-year period from January 1999 to December 2001. These samples were analysed for all the 62 parameters as per the methods prescribed in the Council Directive. Out of the 259 samples analysed 35% of the samples were found to conform to the Directive (Gujarat 53%, Maharashtra 58%, Karnataka 10%, Kerala 36%, Tamil Nadu 24% and Andhra Pradesh 26%). The rest of the samples were found to have one to nine defects. 32% of the samples were found to have one defect (Gujarat 37%, Maharashtra 31%, Karnataka 50%, Kerala 30%, Tamil Nadu 32% and Andhra Pradesh 34%). In all the samples analysed out of the 62 parameters 24 parameters exceeded the MAC prescribed in the Council Directive. The percentage of the samples which exceeded the MAC prescribed for phosphorus is 31 (Gujarat 21%, Maharashtra 19%, Karnataka 50%, Kerala 30%, Tamil Nadu 42% and Andhra Pradesh 29%) and the percentage for 'pesticides & related products' is 29 (Gujarat 16%, Maharashtra 12%, Karnataka 40%, Kerala 31%, Tamil Nadu 39% and Andhra Pradesh 29%). Treatments were suggested to the industry for rectifying the defects and most of the treatments were found to be effective.

Key words : Water quality, process water, seafood processing, India

Water and ice are used for a number of purposes in seafood handling and processing. In seafood handling, water is mainly used for washing the raw material and the containers in which it is packed. In seafood processing, water is used for washing raw materials, utensils, equipments, processing halls, etc. It is used for glazing frozen seafood, preparation of brine and ice manufacture. Water is also used in boilers and in heating / cooling systems. Ice is used for chilling of seafood during handling and at different stages of processing. The utilization of water within the processing plant is detailed by Blackwood (1978). Quantity of water used by seafood processing plants varies with the product. During processing of seafood 0.5 to 10 gallons of water per pound of fish processed may be used (Claggett & Wong, 1974). As per Export Inspection Council (EIC) of India procedure for fixing the capacity of the seafood processing plant at least 10 litres of water is required to process one kg of raw material and 2 kg of ice is required to process one kg of raw material and 1.5 kg ice if the plant is fully air-conditioned.

Most of the uses of water in food industry necessitate certain standards of quality. In many cases, water of the standard of public supplies (IS: 10500, 1991; Anon, 1980; APHA, AWWA & WPCF, 1975; WHO, 1971) is quite satisfactory. But for certain industries water of a more specialized nature (IS: 3957, 1966; IS: 4251, 1967; Blackwood, 1978) is required.

In order to get approval for processing of seafood from EIC of India the water used by the seafood processing plant should satisfy the requirements as per Indian Standard IS: 4251. The water used by the plant should meet the specifications as given in the Council Directive 80/778/EEC (Anon, 1980) Relating to the Quality of Water Intended for Human Consumption in order to export seafood to European Union, as article 2 of the directive states that the directive is also applicable to water used in a food production undertaking for the manufacture, processing, preservation or marketing of products or substances intended for human consumption. The requirements in the directive contain 62 parameters. Out of the 62 parameters, maximum admissible concentration (MAC) is specified for 42 parameters and maximum admissible value is given for 2 parameters. All these quality requirements specified in the directive are given in Table 1. MAC for residual chlorine is not given in the directive. But the directive states that substances used in the preparation of water for human consumption do not, either directly or indirectly, constitute a public health hazard. Hence buyers from European Union specified MAC for residual chlorine as 2000 $\mu g.l^{-1}$, as residual chlorine may constitute public health hazards (Gillies, 1978; Vigneswaran & Viswanathan, 1995; Schneiderman, 1978). In addition to the 62 parameters there are four parameters, which are applicable only to softened water intended for human consumption (Table 1f).

Samples of water from seafood processing establishments located in different regions of India were analysed for the parameters in the Council directive and the results are discussed in the paper. The necessary treatments for the effective rectification of the defects are also described.

Materials and Methods

Two hundred and fifty-nine samples of water were collected from seafood processing establishments located in nine regions of India as per the methods prescribed by Thomas & Mathen (1991) during a period of three years from January 1999 to December 2001. The nine regions were Gujarat, Maharashtra, Karnataka, Kochi, Alappuzha, Kollam (Kerala), Tuticorin, Mandapam, Chennai (Tamil Nadu) and Andhra Pradesh. The number of samples collected were 19, 26, 10, 52, 58, 18, 13, 25 and 38, respectively. The volume of water required for microbiological analysis was 500 ml and that for other parameters 10 l. In addition, a volume of 2 l of water was collected in glass container for estimation of pesticides and related products. These samples were analysed for all the 62 parameters contained in the Council Directive except dissolved or emulsified hydrocarbons, other organochlorine compounds not covered by pesticides and related products (haloform) and polycyclic aromatic hydrocarbons as per the method prescribed in the Council Directive (Anon, 1980). In the case of pesticides and related products, only organochlorine compounds were estimated.

Results and Discussion

Out of the 259 samples of water analysed, 35% of the samples were found to conform to the Directive 80/778/EEC (Gujarat 53%, Maharashtra 58%, Karnataka 10%, Kochi 39%, Alappuzha 36%, Kollam 28%, Tuticorin & Mandapam 31%, Chennai 20% and Andhra Pradesh 26%). The rest of the samples were found to have one to nine defects. 32% of the samples were found to have one defect (Gujarat 37%, Maharashtra 31%, Karnataka 50%, Kochi 29%, Alappuzha 28%, Kollam 44%, Tuticorin & Mandapam 31%, Chennai 32% and Andhra Pradesh 34%). Percentage of the samples of water having different number of defects is given in Table 2. Region-wise number of defects are given in Table 3. Percentage of samples of water which exceeded MAC in each parameter is given in Table 4. In all the samples analysed, out of the 62 parameters 24 parameters exceeded the MAC prescribed in the Council Directive. The percentage of the samples which exceeded the MAC prescribed for phosphorus is 31 (Gujarat 21%, Maharashtra 19%, Karnataka 50%, Kochi 23%, Alappuzha 38%, Kollam 22%, Tuticorin & Mandapam 54%, Chennai 36% and Andhra Pradesh 29%) and the percentage for pesticides & related products is 29 (Gujarat 16%, Maharashtra 12%, Karnataka 40%, Kochi 38%, Alappuzha 21%, Kollam 44%, Tuticorin & Mandapam 8%, Chennai 56% and Andhra Pradesh 29%) Region-wise number of samples of water which exceeded MAC in each parameter is given in Table 5.

Table 1a. Quality requirements of water specified in Council Directive (80/778/EEC) - Organoleptic parameters

Parameters	Expression of the results	Maximum admissible concentration (MAC)
Colour	$mg.l^{-1}$ Pt/Co scale	20
Turbidity	$Mg.l^{-1}$ SiO_2	10
	Jackson units	4
Odour	Dilution number	2 at 12°C
		3 at 25°C
Taste	Dilution number	2 at 12°C
		3 at 25°C

Table 1b. Quality requirements of water specified in Council Directive (80/778/EEC) – Physicochemical parameters

Parameters	Expression of the results	Maximum admissible concentration (MAC)
Temperature	°C	25
Hydrogen ion concentration	pH unit	The water should not be aggressive Maximum admissible value 9.5
Conductivity	$\mu s\ cm^{-1}$ at 20°C	Not specified
Chlorides	Cl $mg.l^{-1}$	Not specified
Sulphates	SO_4 $mg.l^{-1}$	250
Silica	SiO_2, $mg.l^{-1}$	Not specified
Calcium	Ca $mg.l^{-1}$	Not specified
Magnesium	Mg $mg.l^{-1}$	50
Sodium	Na $mg.l^{-1}$	150
Potassium	K $mg.l^{-1}$	12
Aluminium	Al $mg.l^{-1}$	0.2
Total hardness		See Table 1f
Dry residues	$mg.l^{-1}$ after drying at 180°	1500
Dissolved oxygen	$\%O_2$ saturation	Saturation value >75% except for underground waters
Free carbon dioxide	CO_2 $mg.l^{-1}$	The water should not be aggressive

The 62 parameters in the EEC directive are classified into five groups (Tables 1a; 1b; 1c; 1d & 1e). Process water in seafood processing plants should have no noticeable colour, turbidity, odour and taste which are due to the presence of impurities (Taylor, 1958; Tomar, 1999; Train, 1979). Out

Table 1c. Quality requirements of water specified in Council Directive (80/778/EEC) – Parameters concerning substances undesirable in excessive amounts

Parameters	Expression of the results	Maximum admissible concentration (MAC)
Nitrates	NO_3 mg.l^{-1}	50
Nitrites	NO_2 mg.l^{-1}	0.1
Ammonium	NH_4 mg.l^{-1}	0.5
Kjeldahl nitrogen (excluding N in NO_2 and NO_3)	N mg.l^{-1}	1
(K MnO_4) Oxidizability	O_2 mg.l^{-1}	5
Total organic carbon (TOC)	C mg.l^{-1}	Not specified
Hydrogen sulphide	S µg.l^{-1}	Undetectable organoleptically
Substances extractable in chloroform	mg.l^{-1}dry residue	Not specified
Dissolved or emulsified hydrocarbons (after extraction by petroleum ether); Mineral oils	µg.l^{-1}	10
Phenols	C_6H_5OH µg.l^{-1}	0.5 excluding natural phenols which do not react to chlorine
Boron	B µg.l^{-1}	NS
Surfactants (reacting with methylene blue)	µg.l^{-1} (lauryl sulphate)	200
Other organochlorine compounds not covered by parameter No.55	µg.l^{-1}	Haloform concentrations must be as low as possible
Iron	Fe µg.l^{-1}	200
Manganese	Mn µg.l^{-1}	50
Copper	Cu µg.l^{-1}	Not specified
Zinc	Zn µg.l^{-1}	Not specified
Phosphorus	P_2O_5 µg.l^{-1}	5000
Fluoride	F µg.l^{-1}	
	8-12°C	1500
	25-30°C	700
Cobalt	Co µg.l^{-1}	Not specified
Suspended solids		Not specified
Residual chlorine	Cl µg.l^{-1}	*
Barium	Ba µg.l^{-1}	Not specified
Silver	Ag µg.l^{-1}	10

* Necessary measures should be taken to ensure that substances used in the preparation of water for human consumption do not constitute a public health hazard.

of the four organoleptic characteristics (Table 1a), turbidity exceeded the MAC in 0.8% samples (Table 4). Turbidity of water is due to a number of reasons (Taylor, 1958). Appearance of turbidity soon after rain indicates pollution. Water from recently constructed wells contains suspended mineral matter, iron and/or manganese in solution. Turbidity due to iron and manganese is removed by oxidation. Turbidity may also be due to inefficient flushing of the mains especially at dead ends. In general, turbidity can be removed by sedimentation (Vigneswaran & Viswanathan, 1995). Since size of the particles in the surface water is smaller, sedimentation is preceded by flocculation.

Table 1d. Parameters concerning toxic substances (80/778/EEC)

Parameters	Expression of the results	Maximum admissible concentration (MAC)
Arsenic	As $\mu g.l^{-1}$	50
Beryllium	Be $\mu g.l^{-1}$	Not specified
Cadmium	Cd $\mu g.l^{-1}$	5
Cyanides	CN $\mu g.l^{-1}$	50
Chromium	Cr $\mu g.l^{-1}$	50
Mercury	Hg $\mu g.l^{-1}$	1
Nickel	Ni $\mu g.l^{-1}$	50
Lead	Pb $\mu g.l^{-1}$	50 (in running water)
Antimony	Sb $\mu g.l^{-1}$	10
Selenium	Se $\mu g.l^{-1}$	10
Vanadium	V $\mu g.l^{-1}$	Not specified
Pesticides and related products		
i. Substances considered separately	$\mu g.l^{-1}$	0.1
ii. Total	$\mu g.l^{-1}$	0.5
Polycyclic aromatic hydrocarbons	$\mu g.l^{-1}$	0.2

There are fifteen physico-chemical parameters which are given in Table 1b. The significances of these parameters are the following. The maximum admissible temperature (25°C) specified for water in the Council Directive is based on the average ambient temperature in Europe and is not applicable to Indian climatic condition. The significance of temperature in relation to water's natural structure is given by Train (1979). Increase in temperature will reduce the oxygen solubility. On the basis of pH, water can be divided into 3 groups and water having pH values above 8.5 and below 4.5 are generally corrosive (Taylor, 1958; Train, 1979; Tomar, 1999). pH influences the efficiency of disinfection by chlorination (Train, 1979; Anon 1968).

Electrical conductivity of any sample of water depends upon the electrolytes dissolved in it and hence it gives a rough idea about the electrolytes in the water (Adams, 1990; Taylor, 1958). Presence of chlorides imparts taste to water and causes corrosion in hot water systems (WHO, 1971). Water containing an unusual quantity of sodium chloride or sulphate is an indication that the water may be derived from the stratum which contains these salts or there is infiltration of seawater (Taylor, 1958). Sulphate is widely distributed in nature and is relatively abundant in hard waters. Sulphates of sodium and magnesium in excessive amounts cause gastrointestinal irritation (WHO, 1971). There appears to be an inverse correlation between silica content and the abundance of diatoms (Taylor, 1958). Silica has been used in the coagulation process of water treatment (Taylor, 1958). Silicosis resulting from human exposure to silica dust has been a common occupational disease (Manahan, 1993). The general population is not adversely affected by sodium, but various restricted sodium intakes are recommended by physicians for a significant portion of the population (Train, 1979). Potassium occurs in natural waters in far lesser concentration than calcium, magnesium and sodium (Kumar & Kakrani, 2000). Hence a higher level of potassium in water indicates a change in its original structure. Aluminium compounds are used for treatment of water. Water containing 0.2 mg/l of

Table 1e. Microbiological parameters (80/778/EEC)

Parameters	Results: Volume of the sample in ml	Maximum admissible concentration (MAC)	
		Membrane filter method	Multiple tube method (MPN)
Total coliforms	100	0	MPN<1
Fecal coliforms	100	0	MPN<1
Fecal streptococci	100	0	MPN<1
Sulphite-reducing Clostridia	20		MPN=1
Parameters	**Temperature (°C)**	**Sample size (ml)**	**Maximum admissible concentration (MAC)**
Total bacteria counts for water supplied for human consumption	37	1	Not specified
	22	1	Not specified
Total bacteria counts for water in closed containers*	37	1	20
	22	1	100

* Values should be measured within 12 h after putting into closed containers

aluminium (or more) is not suitable for use by kidney dialysis patients (Vigneswaran & Viswanathan, 1995). Aluminium is toxic to brain and is implicated in Alzheimer's disease (McDowell, 1992). Hardness of water causes scale formation. Dry residues may produce taste and gastrointestinal irritation (WHO, 1971). Total dissolved solids may cause corrosion and impart unpalatable mineral taste (Train, 1979). Dissolved oxygen is desirable as an indicator of satisfactory water quality in terms of low residuals of biologically available organic materials (Train, 1979). The presence of free carbon dioxide in water makes the water aggressive (Anon, 1980; Taylor, 1958).

Table 1f. Minimum required concentration for softened water intended for human consumption (80/778/EEC)

Parameters	Expression of the results	Minimum admissible concentration (MAC)
Total hardness	mg.l^{-1} Ca	60
Hydrogen ion concentration	pH	Water should not be aggressive
Alkalinity	mg.l^{-1} HCO_3	30
		Water should not be aggressive
Dissolved oxygen	mg.l^{-1}	Water should not be aggressive

Five characteristics under physico-chemical parameters exceeded the limit (Table 4). Sulphate, sodium, potassium and dry residues can be removed by deionizer (Gillies, 1978). Aluminium can be removed by chitosan (Wetrowski, *et al.*, 1994).

There are 24 parameters under substances undesirable in excessive amounts (Table 1c). The significance of these parameters are as follows. Nitrates are present in most waters. Their only concern with purity and wholesomeness relates to consideration of pollution by sewage or manure, since they may be derived from the oxidation of organic matter of animal origin. The more efficient the process of sewage purification, the less is the amount of nitrogen as free ammonia, and the greater the amount of nitrogen as nitrites and nitrates (Taylor, 1958). The high contents of ammonium, Kjeldahl nitrogen, oxidizability and phosphorus may be due to eutrophication (Kandadai, 1995). Organic carbon present in water may be converted to organochlorine compounds especially haloforms during chlorination of water. Hydrogen sulphide may be present in bore well waters and it is removed, when the water is exposed to air (Taylor, 1958). Substances

Table 2. Percentage of the samples of water having defects in quality parameters with reference to Council Directive 80/778/EEC

Number of defects	Percentage
Zero	35.1
One	32.4
Two	14.3
Three	10.0
Four	2.7
Five	2.7
Six	0.8
Seven	0.4
Eight	1.2
Nine	0.4

extractable in chloroform is a measure of dissolved and emulsified oil and grease present in water. Drinking water supply should be virtually free from oil and grease, particularly from the tastes and odours that emanate from petroleum products (Train, 1979). Natural phenols may be present in water (Anon, 1980). Synthetic phenols are attributed to wastes from chemical industry (Clark. *et al.* 1977). Presence of phenol (excluding natural phenols which do not react to chlorine) in water may produce taste, particularly when the water is chlorinated. Boron is an essential element for growth of plants but there is no evidence to show that it is required by animals (Train, 1979). The presence of surfactants in water indicates that the water is polluted with wastewater previously used for washing purposes. Chlorination of drinking water containing organic substances is the major factor in the formation of trihalomethanes (haloforms) in treated drinking water and the compounds are toxic (Gillies, 1978). Soluble iron and manganese are found in many ground waters because of reducing conditions which favour the soluble +2 oxidation state of these metals (Manahan, 1993). When these waters are exposed to air, turbidity, colour and precipitate are developed due to the oxidation of these metals (Taylor, 1958; Manahan, 1993). Copper in excess of $1 mg.l^{-1}$ may impart some taste to water (Train, 1979). Zinc in water produces undesirable aesthetic effects (Train, 1979). The use of phosphate based fertilizers and detergents increases the chances of contamination of drinking water. Fluoride is a natural mineral contaminant of water. Fluoride in large quantities is harmful for humans and other animals, but is beneficial if present in low concentrations (Tomar, 1999). Cobalt is an essential element as a component of vitamin B_{12}. Excessive intake of cobalt may be toxic (Gillies, 1978). Suspended solids provide areas where microorganisms do not come into contact with the chlorine disinfectant during chlorination of water (Train, 1979). Residual chlorine present in water may react with organic matter producing organochlorine compounds which are carcinogenic. It is rare to find barium in drinking water at a concentration in excess of 1mg.l-1 because of the low solubility of barium sulphate and the limit of 4mg.l^{-1} is based on organoleptic factors (Gillies, 1978). Biologically, silver is a non essential element and ingestion of silver or silver salts by humans causes a blue-gray discolouration (Train, 1979).

Table 3. Defects in water quality parameters, region - wise

Region	Gujarat	Maha-rashtra	Karna-taka	Kochi	Ala-ppuzha	Kollam	Tuti-corin & Mandapam	Chennai	Andhra Pradesh
No. of samples collected	19	26	10	52	58	18	13	25	38
No. of samples with zero defect	10	15	1	20	21	5	4	5	10
No. of samples with one defect	7	8	5	15	16	8	4	8	13
No. of samples with two defects	0	2	1	8	13	2	2	4	5
No. of samples with three defects	2	1	1	5	4	1	3	6	3
No. of samples with four defects	0	0	1	0	3	0	0	1	2
No. of samples with five defects	0	0	0	1	1	1	0	0	4
No. of samples with six defects	0	0	1	0	0	1	0	0	0
No. of samples with seven defects	0	0	0	0	0	0	0	1	0
No. of samples with eight defects	0	0	0.	3	0	0	0	0	0
No. of samples with nine defects	0	0	0	0	0	0	0	0	1

Out of the 24 parameters included in Table 1c, 9 parameters exceeded the MAC (Table 4). In the case of phenols the value includes that of natural phenols also. Ammonium can be removed from water by passing through

Table 4. Defects in water quality parameters and their percentage of incidence

Parameters which exceeded the MAC	Percentage of samples which exceeded the MAC
a. Organoleptic parameters	
Turbidity	0.8
b. Physico-chemical parameters	
Magnesium	2.3
Sodium	5.4
Potassium	4.3
Aluminium	0.8
Dry residues	2.3
c. Parameters concerning substances undesirable in excessive amounts	
Ammonium	4.6
Kjeldahl nitrogen	1.2
($KMnO_4$) Oxidizability	1.2
Phenols	10.4
Iron	0.8
Manganese	3.1
Phosphorus	30.5
Fluoride	1.2
Residual chlorine	2.3
d. Parameters concerning toxic substances	
Cadmium	1.2
Nickel	1.2
Lead	1.5
Pesticides & related products	29.0
e. Microbiological parameters	
Total coliforms	3.5
Faecal coliforms	2.7
Faecal streptococci	0.4
Sulphite-reducing Clostridia	9.7
Total bacteria counts for water in closed containers	15.4

deionizer (Gillies, 1978), oxidation with chlorine (Anon, 1968) or by passing through a bed of activated carbon, Kjeldahl nitrogen and oxidizability can be removed by oxidation with chlorine (Anon, 1968) or treatment with calculated amount of alum (Clark *et al.*, 1977). Phenols can be removed by treatment with chitosan or passing through activated carbon (Gillies, 1978). The basic method for removing both iron and manganese depends upon oxidation to higher insoluble oxidation states. The oxidation is

Table 5. Region wise distribution of defects in water quality parameters which exceeded the MAC

Parameters which exceeded MAC	Number of samples which exceeded the MAC in each parameter in different regions								
	Gujarat	Maha-rashtra	Karna-taka	Kochi	Ala-ppuzha	Kollam	Tuti-corin & Mandapam	Chennai	Andhra Pradesh
Turbidity	0	0	0	1	1	0	0	0	0
Magnesium	1	0	1	2	0	1	0	0	1
Sodium	1	1	1	2	3	1	0	2	3
Potassium	0	1	1	2	3	1	1	1	1
Aluminium	0	0	0	1	0	0	0	0	1
Dry Residues	1	0	1	2	0	1	0	0	1
Ammonium	0	0	1	1	4	2	0	3	1
Kjeldahl Nitrogen	0	0	1	0	1	0	0	1	0
(KM_nO_4) Oxidizability	0	0	0	1	2	0	0	0	0
Phenols	1	0	1	6	9	0	2	2	6
Percentage	**8**	**0**	**10**	**12**	**16**	**0**	**15**	**8**	**16**
Iron	0	0	0	1	0	0	0	0	1
Manganese	0	0	1	3	3	0	0	1	0
Phosphorus	4	5	5	12	22	4	7	9	11
Percentage	**21**	**19**	**50**	**23**	**38**	**22**	**54**	**36**	**29**
Fluoride	0	0	0	0	2	0	0	0	1
Residual Chlorine	0	0	1	2	2	1	0	0	0
Cadmium	0	0	0	1	1	1	0	0	0
Nickel	0	0	0	1	0	0	0	1	1
Lead	0	0	0	1	0	0	0	0	3
Pesticides and related products	3	3	4	20	12	8	1	14	10
Percentage	**16**	**12**	**40**	**38**	**21**	**44**	**8**	**56**	**29**
Total coliforms	0	0	0	2	0	1	0	1	5
Faecal coliforms	0	0	0	1	0	1	0	1	4
Faecal streptococci	0	0	0	0	0	0	0	0	1
Sulphite-reducing Clostridia	2	2	0	6	2	1	2	5	5
Percentage	**11**	**8**	**0**	**12**	**3**	**6**	**15**	**20**	**13**
Total bacteria counts for water in closed containers	0	3	2	7	4	3	4	4	13
Percentage	**0**	**12**	**20**	**13**	**7**	**17**	**315**	**16**	**34**

generally accomplished by aeration; chlorine and potassium permanganate are sometimes employed as oxidizing agents (Clark *et al.*, 1977; Manahan, 1993). These metals can also be removed by addition of sodium carbonate or lime (Manahan, 1993). Phosphorus can be removed by treating with calculated amount of lime/$Ca(OH)_2$ (Kandadai, 1995; Clark *et al.*, 1977). Fluoride in drinking water can be removed by coagulation (alum, lime and magnesium compounds such as dolomite are the commonly used coagulants) and co-precipitation (calcium phosphate is used as the co-precipitant) followed by sedimentation and adsorption on activated carbon, bone char, ion exchange resins, synthetic zeolite or activated alumina (Vigneswaran & Visvanathan, 1995). Excess of chlorine, both free and combined, remaining in the treated water can be removed by the addition of chemicals such as sulphur dioxide and sodium thiosulphate or by filtration through a bed of activated carbon (Taylor, 1958).

There are 13 parameters concerning toxic substances (Table 1d). The significances of these parameters are the following. Arsenic is a cumulative poison (Train, 1979). Beryllium is unlikely to occur in drinking water at more than trace concentrations and beryllium produces acute or chronic toxicity in animals when ingested continuously as beryllium sulphate in water at concentrations greater than 5 $mg.l^{-1}$ (Gillies, 1978). Cadmium is also a cumulative poison. Drinking water containing excessive cadmium led to the occurrence of *itai-itai* disease among Japanese (Train, 1979). Cyanide ingested by humans through water at quantities of 10mg or less per day is not toxic and lethal toxic effects from the ingestion of water containing cyanide occur only when cyanide concentrations are high and overwhelm the detoxifying mechanisms of the human body (Train, 1979). Microgram amounts of chromium are essential for maintenance of normal glucose metabolism; but hexavalent chromium is known to be toxic (Gillies, 1978). Mercury is a cumulative poison. There is no indication that concentrations of mercury in drinking water have contributed in any significant way to methyl mercury intoxication of the general population (Gillies, 1978). Nickel in various forms is relatively nontoxic when consumed; but workers exposed to air borne nickel have an increased incidence of respiratory disease and cancer (McDowell, 1992). Lead has no beneficial or desirable nutritional effects and is a cumulative poison. The maximum tolerable level of dietary antimony for rabbit is 75-100 ppm (Mc Dowell, 1992). Selenium is considered toxic to man (Train, 1979). Selenium is also considered as an essential nutrient. The beneficial and adverse effects depend on the amount ingested, the form of selenium, the presence of other trace elements, etc. (Gillies, 1978). Occupational exposure to pentoxides and trioxides of vanadium leads to ear, nose and throat irritation; but there is no evidence of chronic oral toxicity (Gillies, 1978). Synthetic organic contaminants in drinking water constitue a public health concern (Gillies, 1978). Pesticides and related products are insecticides (organochlorine compounds, organophosphorus compounds and carbamates), herbicides, polychlorinated biphenyls (PCBs) and polychlorinated triphenils (PCTs) (Anon, 1980). Pesticides are employed for many different purposes. Insecticides are used in the control of insects; herbicides used against plants and fungicides against fungi. Pesticides in general are carcinogens. PCBs are used principally in the electrical industry in capacitors and transformers (Train, 1979). PCBs have been found through out the world in water (Manahan, 1993). Exposure to PCBs is known to cause skin lesions in humans and to increase liver enzyme activity (Train, 1979). PCTs have almost identical characteristics to high chlorinated PCBs. It is used as a substitute for PCBs. PCTs have been detected in water. Polycyclic aromatic hydrocarbons (PAH) are formed by the incomplete combustion of other hydrocarbons and are encountered abundantly in the environment. Some PAH compounds are precursors to cancer-causing metabolites (Manahan, 1993).

Out of the 13 parameters included in Table 1d, four parameters exceeded the MAC (Table 4) in the samples analysed. Heavy metals such as copper, cadmium, mercury and lead can be removed by lime treatment, ion exchange, activated carbon adsorption, treatment with chitosan etc. (Manahan, 1993; Martin, 1974; Masri & Randall, 1978). Most of the pesticides and related products can be removed from water by passing through activated carbon, packed tower aeration or treatment with chitosan (Gillies, 1978; Weltrowski, *et al.,* 1994; Das, 2000).

There are six characteristics under microbiological parameters (Table 1e). Coliforms, faecal streptococci and *Clostridium perfringens* (sulphite-reducing Clostridia) are indicator organisms. The presence of these organisms in water is an indication of fecal contamination. The presence of fecal organisms in a water sample indicates that pathogens could be present and the absence indicates that pathogens also are probably absent. *Clostridium perfringens* form spores which survive for a much longer time than vegetative organisms. Total bacterial counts are useful for indicating the efficiency of certain processes in water treatment and the cleanliness of the distribution system.

Out of the six parameters in the group E, five exceeded the limit (Table 4) in the samples analysed. All the defects except the presence of suphitereducing Clostridia can be rectified by proper chlorination of water. Dechlorination of water, by passing through activated carbon, is necessary if the chlorine level of the water exceeds 2000 μg.l^{-1}. (Taylor, 1958). It is difficult to remove sulphite-reducing Clostridia by superchlorination as the organism forms spores. However, thorough cleaning of the storage tanks and supply lines followed by sanitation with chlorine/ozone was found to be effective.

The defects of the samples of water were studied in detail by resampling and analysis. If the parameters exceeded the MAC even after resampling and analysis, the treatments cited above were suggested to the industry. The treatments suggested were found to be effective in rectifying the defects.

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