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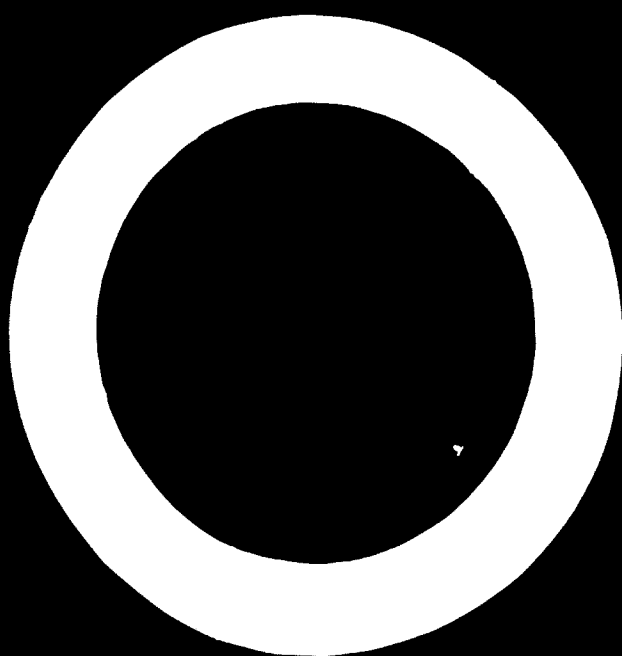For more information about UNIDO, please visit us at www.unido.org

WATER-SAVING TECHNIQUES IN FOOD-PROCESSING PLANTS
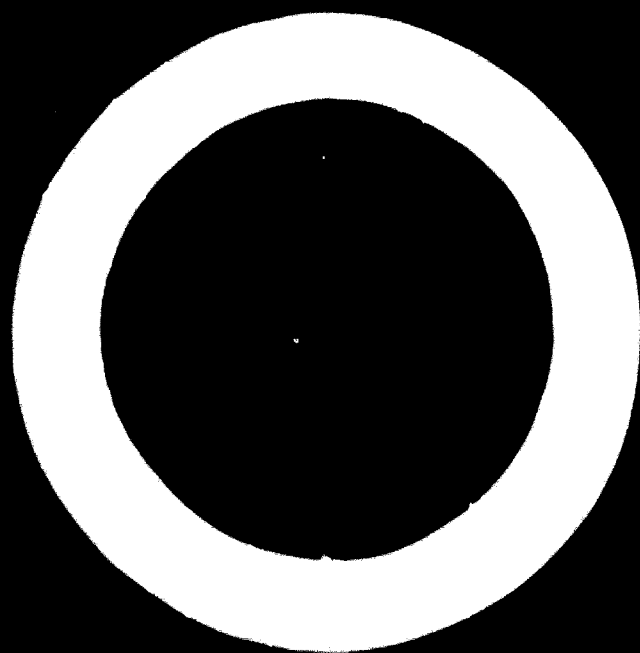
FOOD INDUSTRY STUDIES No. 3

UNITED NATIONS

WATER-SAVING TECHNIQUES IN FOOD-PROCESSING PLANTS

In this publication. ID/SER. 1/3, the following should be corrected:

Page 1,   in the last sentence "oxygen" should read "carbon dioxide".

Page 2,   in the fourth line from the bottom of the page NO_2 should read NO_2.

Page 11,   *Table 3,* in the last line of the "calcium" column "118" should read "218".

Page 14,   in the sixth line of the sixth paragraph *delete* "tanning", remove the parenthetical marks in the sixth and seventh lines, and change "shells" to "skins".

Page 19,   *Table 10,* in the heading of the second column *delete* "(Durchlauf-kessel)".

Page 47,   in sub-paragraph (j), line 3, KIO_3 should read $K_2Cr_2O_7$.

Page 52,   in the first line of the fourth paragraph *delete* "poisonous".

Page 53,   *Table 23,* in the first line "(m^3/t) of beets" should read "$(m^3/t$ of beets)"; in the third line "Volatile matter (%)" should read "Volatile matter (as % of dry residue)".

Table 24, in the second line "Ignition residue" should read "Fixed solids".

Page 54,   *Table 25,* in line 8 "Ignition residue" should read "Fixed solids" and in line 9 "Loss by ignition" should read "Volatile matter".

Table 26, in line 7 "Ignition residue" should read "Fixed solids", and in line 8 "Loss by ignition" should read "Volatile matter".

Page 58,   *Table 28,* in line 11 "biofilter" should read "biofiltration", and in line 13 *insert* "treatment" after "carbon".

In the last line of page 58 "into" should read "in".

WATER-SAVING TECHNIQUES

IN FOOD-PROCESSING PLANTS

WATER-SAVING TECHNIQUES
IN FOOD-PROCESSING PLANTS

CONTENTS

mg = milligram

g = gram

l = litre

meq = milligram equivalent

ppm = parts per million

t = metric ton

ml = millilitre

FOREWORD

This monograph is one of a series of studies designed for the use of the food-processing industries of developing countries. The approach used and the criteria followed are based on the concept that processes and techniques must be adopted that will produce goods that can compete in quality, price and reliability of supply with goods from countries whose industrialization began earlier. This concept is considered valid even when capital for investment and skilled labour may be in short supply and present markets for the products limited or even non-existent. No country, and especially no developing country, can afford to waste its resources by building industries whose products are too high in price and/or too low in quality to gain acceptability in the world market.

The objective of UNIDO in publishing this series of studies in the food-processing industry is therefore to help the developing countries to gain good technical insights into selected areas of food processing and to avoid obsolescent procedures and processes. It is hoped that these studies will provide reliable and practical information for governmental authorities and for potential private and institutional investors.

The present monograph was prepared by Mr. Lavoslav Richter of the Institute for Processing Techniques, Zagreb, Yugoslavia, in the capacity of consultant to UNIDO. The views and opinions expressed in this publication are those of the consultant and do not necessarily reflect the views of the secretariat of UNIDO.
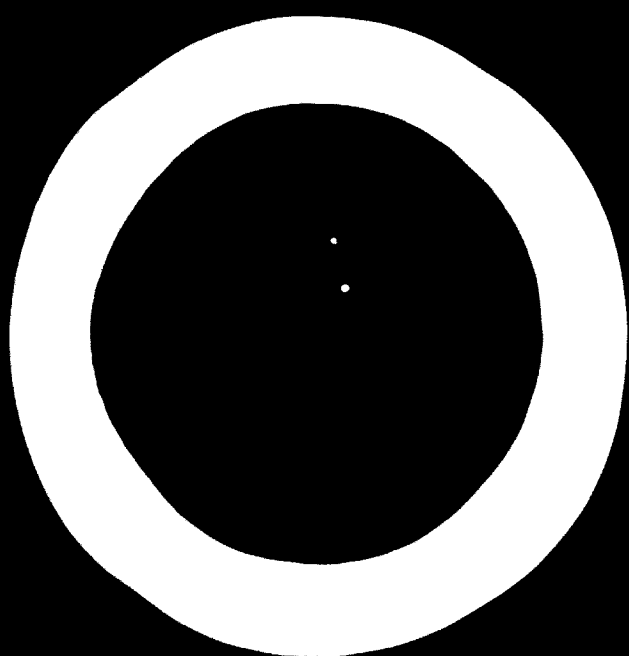
INTRODUCTION

The consumption of water in the world today has been greatly increasing because of the population explosion, higher standards of public health, and the expansion of industry. At the same time nature's precious gift of pure water has not only been wastefully exploited but also has been increasingly contaminated by sewage from towns and industrial waste. This contamination is a striking illustration of the way in which man's social activity is changing his environment.

Industrial food-processing plants are one of the major consumers of industrial water. Water is for them a technological raw material. It is used as a solvent in various technological processes, for washing and cooling, and as a heat-transmission agent.

The specific demands in regard to the quality of water depend upon the specific characteristics of the technological process. The properties of water in its unprocessed state rarely meet these needs. In most cases additional treatment is necessary before letting the water into the production process.

Draining the water already used in the process into the normal sewage or river-beds also presents a big problem. Contamination of the natural water systems is daily increasing, and for the sake of public health more attention must be devoted to water purification in the future. For economic purposes used water is being treated at an ever increasing rate and where possible recirculated into the process.

Discovering the most economical methods of shipping water into food-processing industrial plants, the successful treatment of sewage waters, and the most efficient manner of water processing are today an urgent matter for industry.
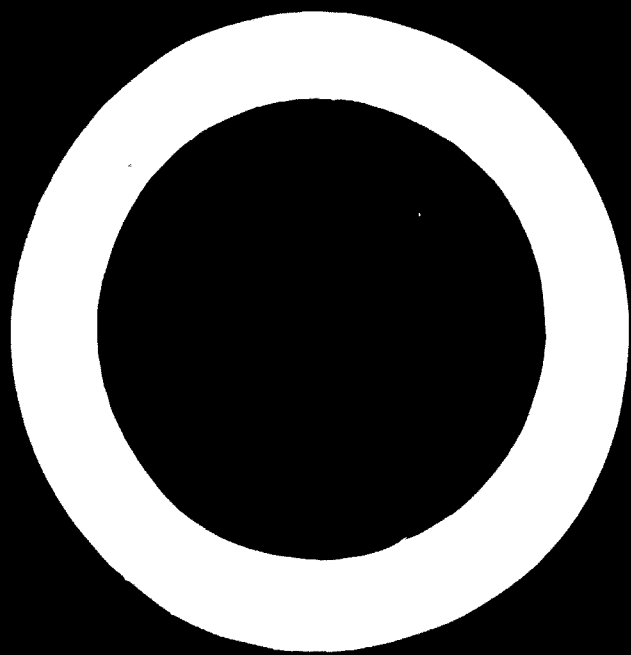
KINDS OF WATER, SOURCES AND SUPPLY

According to the form in which water appears in nature, it is possible to distinguish atmospheric, surface, underground and salt water.

Atmospheric water represents the purest water with respect to the amount of admixtures dissolved in it. However, it too contains impurities including gases (oxygen, nitrogen, carbon diox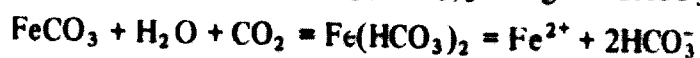ide) that it gets from the air and organic and inorganic matter whose composition and quantity depend on the composition of the atmosphere. Atmospheric water in inhabited areas and industrial centres contains sulphuric oxide, soot and dust particles. The total salt concentration usually does not exceed 50 mg/l.

Surface, underground and sea water contain more minerals than are found in atmospheric water, and in most cases cannot be applied directly in technological processes without preliminary treatment. The surface water of lakes, rivers and accumulation systems for industrial use always contain dissolved matter and insoluble mechanical admixtures.

Water becomes saturated on the ground surface by suspended matter, impurities and organic substances; in passing through the underground mineral layers it is filtered and freed from coarse mechanical admixtures and at the same time is enriched by salts, gases and organic ingredients derived from decomposed vegetable and animal organisms.

Oxidation of organic matter in the soil causes consumption of oxygen and yields carbon dioxide. This has significance in enriching water with poorly soluble carbonates.

Exceptional water-enriching agents are sediment depositions of limestone, dolomite and gypsum. Underground water dissolves $NaCl$, Na_2SO_4, $MgSO_4$ and other easily soluble salts. The process of enriching water with carbonates of calcium $(CaCO_3)$, magnesium $(MgCO_3)$, and iron $(FeCO_3)$ takes place according to the formulae:

$$CaCO_3 + H_2O + CO_2 = Ca(HCO_3)_2 = Ca^{2+} + 2HCO_3^-$$

$$MgCO_3 + H_2O + CO_2 = Mg(HCO_3)_2 = Mg^{2+} + 2HCO_3^-$$

$$FeCO_3 + H_2O + CO_2 = Fe(HCO_3)_2 = Fe^{2+} + 2HCO_3^-$$
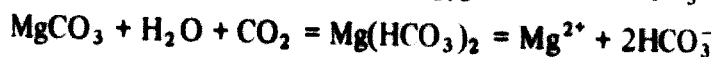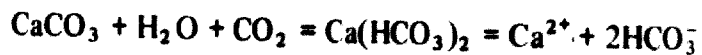
As a result of these reactions readily soluble bivalent salts, bicarbonates of calcium, magnesium and iron that dissociate into cations Ca^{2+}, Mg^{2+} and anion HCO_3^- are formed.

At normal temperatures these salts are dissolved in water, while at higher temperatures they yield corresponding carbonates which deposit on the surface of tubes, apparatus and fixtures, simultaneously giving off oxygen.

1

Underground water, which on its passage through various layers is enriched with mineral ingredients, appears later on the surface clean, free from mechanical admixtures, but as a rule has a greater content of mineral salts than surface water

Of all natural water the oceans, seas and salt lakes contain the greatest quantities of soluble salts

Besides the natural circular flow of water, industrial systems for the consumption and exploitation of water also exist

The need for water in different branches of industry for feeding boilers, cooling, technological requirements, washing, etc. is met by diverting water from natural sources, such as rivers, underground flows, seas and lakes and using pumps and pipelines to bring it to consumers. When this water has served its purpose, it is returned to the rivers as waste. This discharge is always degraded in quality in comparison to the intake phase. Oil refineries, food-processing plants, and metal and metallurgical industries in particular lower the quality of the exploited water

Through the continuous discharge of the exploited waters, the general quality of the raw, natural waters in the vicinity of industrial centres and inhabited areas constantly deteriorates, and stricter control is required. The ever-growing problem of pollution of raw water requires correspondingly more dependable and complicated processing equipment.

Characteristics of natural water

Admixtures in natural water

All admixtures found in natural water as a result of its circular movement in nature can be divided into three groups with regard to the degree of dispersion: (a) coarse particles larger than 100 millimicrons; (b) colloidal particles of 1 100 millimicrons; (c) molecular particles in the range below 1 millimicron

Coarse particles and colloids form with water a heterogeneous system, i.e. a border exists between the liquid and solid phases, while particles molecularly dispersed in solution form a homogeneous system. Between these two categories there are no sharp demarcation lines.

Coarsely dispersed matter, which causes turbidity of natural water, consists of sand, clay, and other particles of mineral and organic origin that are washed off the ground surface during heavy rains, snow thawing, or river floods.

Natural water is still transparent when the concentration of coarsely dispersed matter is less than 5 mg/l. These particles eventually settle down in water when their density is greater than that of water.

Colloidally dispersed matter, according to the dimensions of the particles, occupies the transition position between the coarsely and molecularly dispersed systems. It is not subject to sedimentation, not even after long periods of time. Colloids in natural water consist of the compounds of silicon, aluminium, iron and also of the organic matter resulting from the decomposition of plant and animal organisms.

Salt, acid and base solutions constitute the molecularly dispersed systems. The most common ions in natural water are: Ca^{2+}, Mg^{2+}, Na^+, Cl^-, SO_4^{2-}, HCO_3^-, $HSiO_3^-$. Other ions such as CO_3^{2-}, H^+, OH^-, NH_4^+, NO_2^-, NO_3^-, Fe^{2+}, Cu^{2+} are usually to be found in natural water only in traces, although they sometimes decisively influence the properties of water and its behaviour at high temperatures: in boilers, during cooking in food processing, and on cooling surfaces.

Calcium ions are the most abundant in water not containing large amounts of salts (weakly mineralized waters). The basic source of calcium ions in raw water is limestone which is composed of calcium carbonates and which is soluble under the influence of carbon dioxide from water.

Water is enriched by the ions of calcium and gypsum ($CaSO_4 \cdot 2H_2O$).

Magnesium ions enter raw water primarily as a result of the decomposition of dolomites ($MgCO_3$, $CaCO_3$) in the presence of free carbon dioxide in water.

With an increasing degree of mineralization of raw water the relative content of calcium ions drops. Owing to water evaporation the concentrations of calcium carbonate and calcium sulphate grow, and the solid state precipitates out of the solution.

Because of the greater solubility of magnesium sulphate the magnesium ions can be contained in natural water in great concentrations, which in very mineralized water reach up to several grams per litre.

Of the alkaline metals, sodium is the most abundant in natural water. The concentration of sodium ions mounts with the increase of the mineral content of water.

Chlorine ions are present in almost all natural water, and their content varies throughout a wide range. Similar to sodium ions, chlorine ions are most characteristic of water with a very high salt content.

Sulphate ions, like chlorine ions, are very widespread. In underground water the sulphate concentrations are usually far greater than in lake and river water. The basic source of sulphate ions is gypsum.

Hydrogen (H^+) and hydroxyl (OH^-) ions are present in water as a result of water dissociation:

$$H_2O \rightleftharpoons H^+ + OH^-$$

Hydrogen ions are found in water also because of the acid dissociation: $HCl = H^+ + Cl^-$, and hydroxyl ions as a product of the alkali dissociation: $NaOH = Na^+ + OH^-$.

In chemically pure water at a temperature of $23°C$ the concentration of ions (H^+) and (OH^-) is equal to 10^{-7} g ion/l and characterizes the neutral reaction of the liquid. In an acidic medium the following condition prevails:

$$[H^+] > 10^{-7} > [OH^-] \text{ and in a base: } [OH^-] > 10^{-7} > [H^+]$$

It is more convenient to express the reaction in a solution in the form of pH and pOH indicators, either of which represents a negative logarithm of the corresponding concentrations. In a neutral medium pH = 7 = pOH.

An acidic environment is characterized by the inequality pH < 7 < pOH and an alkaline one by pH > 7 > pOH.

Carbonic acid of bivalence dissociates in two phases:

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$

In natural water bicarbonate ions and in some cases carbonate ions can be found in addition to the so-called "free carbonic acid" found in the form of dissolved CO_2-gas and undissociated molecules of carbonic acid H_2CO_3.

Quantitative ratios between CO_2, H_2CO_3, HCO_3^-, and CO_3^- determine the pH of water. These interdependencies are shown in table I below.

TABLE I

PERCENTAGES OF VARIOUS FORMS OF CARBONIC ACID IN WATER AT $25°C$

Form of carbonic acid	pH								
	4	5	6	7	8	9	10	11	12
CO_2, H_2CO_3	100	95	70	20	2	--	--	--	--
HCO_3^-	--	5	30	80	98	95	70	17	2
CO_3^{2-}	--	--	--	--	--	5	30	83	98

In water solutions there exists a kinetic equilibrium between the various forms of carbonic acid: $2HCO_3^- \rightleftharpoons CO_3^{2-} + H_2O + CO_2$. From this equation it follows that for the maintenance of a particular concentration of a bicarbonate ion there should exist in the water a corresponding concentration of free carbon dioxide (CO_2). If the actual content of free carbonic acid in the water is higher than the equilibrium-maintaining concentration, its surplus is able to produce the dissolution of calcium carbonate when in contact with limestone dolomites. Such water is "aggressive". On the other hand, a shortage of CO_2 in the water leads to the decomposition of carbonate ions, i.e. to the shifting of the equilibrium to the left.

Compounds of nitrogen are found in natural water in the form of ammonium ions (NH_4^+), nitrate and nitrite ions. The basic sources of these ions are the products of decomposition of organic matter of plant and animal origin. In addition, the ammonium ions enter the water by way of residual water. In the presence of a sufficient amount of oxygen and a particular kind of bacteria the ammonium ions are oxidized into nitrite ions and further into nitrate ions. In this way the nitrite and nitrate ions are the end-product of a complex process of organic matter mineralization.

Iron compounds are found in natural water as bivalent and trivalent ions. These compounds can be in the form of real solutions, colloids and suspensions.

Underground water contains predominantly iron bicarbonate ($Fe(HCO_3)_2$), which is easily hydrolyzed and oxidized in the presence of oxygen in the water. In surface water iron is found in the form of complex organic compounds or as a hydroxide of trivalent iron ($Fe(OH)_3$). Iron can be found in natural water partly as a result of industrial waste water.

Silicon compounds are present in water in various degrees of dispersion. Silicic anhydride is capable of combining with various quantities of water, thus forming various acids of a general formula: $m\ SiO_2 \cdot n\ H_2O$. The salts of these acids yield a series of minerals whose dissolution in natural water produces compounds of silicic acids of varying composition.

The solubility of silicic acids in natural water depends on a series of factors and, first of all, on the ionic composition of the water and pH. The presence of cations, calcium and magnesium in the water causes the formation of poorly soluble silicates and lowers the concentration of silicic acid in the solution. The presence of sodium cations in the water and an increase of pH increase the solubility of silicic acids. In surface water (rivers, lakes and accumulation systems, canals) and also in underground water the silicon content rated as SiO_3^{2-} generally falls in the range 0.6- 40 mg/l, and only in exceptional cases reaches the value of 65 mg/l. A part of the silicic compounds is found in a colloidal state as particles of polysilicic acid. Tests have shown that the quantity of colloidal forms of this acid ranges from 3 to 15 per cent of its total content in the water.

In natural water the cations Al^{3+}, Mn^{2+} and very rarely K^+ can also be found.

The most widespread gases in water are nitrogen, oxygen and carbon dioxide. The solubility of gases in water depends on temperature and the partial pressure of the gas in question in the space above the water.

The source of oxygen in natural water is the atmosphere; the oxygen from the air penetrates the water when the two media touch. The oxygen content is regulated by its pressure in the atmosphere, while in the water it is consumed in various oxidation processes.

Carbon dioxide in water appears as a product of the oxidation of organic matter in the water itself and in the ground through which the water penetrates. In deep water larger quantities of CO_2 can result from the chemical reactions related to the change of the mineral content. The carbonic acid content can be reduced because a part of the carbon dioxide escapes from the water into the atmosphere or because chemical compounds are formed between carbon dioxide and carbonates of calcium and magnesium from limestone and dolomite.

Water quality indicators

The most important quality indicators for the water used in the food-processing industry are: composition of the suspended matter, solids, total hardness and its components, total alkalinity with its components, ability to oxidize, concentration of hydrogen ions, the composition of the gases dissolved in the water and the microbiological state of the water.

Suspended matter soils the water with hard, insoluble mixtures, the quantity of which is expressed in mg/l of water.

By dry residue of water is meant the total amount of non-soluble non-evaporative molecularly dispersed and colloidal matter of mineral and organic composition alike, and is expressed in mg/l of water. It is determined by evaporating the previously filtered water sample and the subsequent drying of the residue at $110°C$ until constant weight is reached. If the dry residue is ignited at $800°C$ its weight decreases, and it becomes a fixed residue. The weight reduction is a result of the decomposition of organic matter and destructible carbonates and of total water evaporation.

Mineral residue is the total amount of all cations and anions as well as of the oxides Fe_2O_3 and Al_2O_3.

Water hardness is one of the most important water quality indicators, regardless of the purpose for which the water is used. Total hardness is the sum of the concentrations of cations of calcium (calcium hardness) and magnesium (magnesium

hardness) expressed in meq/l or gram-equivalent/m³. Water hardness is also expressed in German, French or English hardness degrees. For example, 1 German hardness equals 10 mg/l, or 10 ppm of CaO. Table 2 gives the relationships between the values of the several degrees of water hardness.

TABLE 2

DEGREE OF WATER HARDNESS

1° German	1.79° French	1.25° English	10.0 ppm [a] CaO
1° French	0.70° English	0.56° German	7.0 ppm CaO
1° English	0.80° German	1.43° French	8.0 ppm CaO

[a] ppm = parts per million = mg/l.

$$meq/l = \frac{mg/l}{equivalent\ weight}$$

For computing calcium and magnesium concentration the following ratios are used:

$$calcium\ hardness = \frac{(Ca^{2+})}{20.04}(meq/l)$$

$$magnesium\ hardness = \frac{(Mg^{2+})}{12.16}(meq/l)$$

where (Ca^{2+}) and (Mg^{2+}) denote the concentration of calcium and magnesium ions in water, given in ppm, and 20.04 and 12.16 are the equivalent weights of calcium and magnesium.

Total hardness of water is divided into bicarbonate and non-carbonate hardness. Bicarbonate hardness is characterized by the presence of calcium and magnesium bicarbonates, as well as by the carbonates of all minerals that are poorly soluble in water. Non-carbonate hardness (permanent hardness) results from the presence of chloride, sulphate, and other non-carbonate salts of calcium and magnesium, such as $CaCl_2$, $MgCl_2$, $CaSO_4$, $CaSiO_3$, $MgSO_4$, $MgSiO_3$. The total hardness of water may be expressed either as the sum of the bicarbonate and non-carbonate hardness, or as the sum of calcium and magnesium hardness. Occasionally natural water occurs with the concentration of HCO_3 expressed in meq/l being greater than total hardness. In such cases total hardness is equal to the bicarbonate hardness, and permanent hardness is zero. The difference between the bicarbonate and the total hardness is attributable to the sodium bicarbonates in the water.

According to the grade of total hardness an approximate classification of water has been established as follows:

Total hardness (meq/l)	Classification
0 – 1.5	very soft
1.5 – 3.0	soft

Total hardness (meq/l)	Classification
3.0 – 6.0	average hard
6.0 – 12.0	hard
over 12.0	very hard

Alkalinity is usually imparted by the bicarbonate and hydroxide components of a natural or treated water supply expressed in meq/l. It is determined by titration with a standard solution of a strong mineral acid, using phenolphthalein as the indicator. This amount of the acid enables the measurement of that alkalinity fraction contributed by the hydroxide and half of the carbonate present in the water

Titration with a standard mineral acid solution indicated by methyl orange determines the total alkalinity of the water.

The results obtained from the phenolphthalein and total alkalinity determinations offer a means for the stoichiometric classification of the three principal forms of alkalinity of many water supplies:

(a) Carbonate alkalinity is present if the phenolphthalein alkalinity is greater than zero but less than the total alkalinity.

(b) Hydroxide alkalinity is present if the phenolphthalein alkalinity is more than half the total alkalinity.

(c) Bicarbonate alkalinity is present if the phenolphthalein alkalinity is less than half the total alkalinity.

Since direct determination of the concentration of organic matter in water is practically impossible, its content is measured indirectly, determining the so-called water oxidizability expressed as the quantity of standard potassium permanganate ($KMnO_4$) solution consumed during titration in an acidic medium. This solution of $KMnO_4$ can oxidize not only the organic matter in the water but some easily oxidizable matter of mineral origin as well. Therefore oxidizability characterizes the content of organic matter only approximately; essentially, it characterizes the presence of easily oxidizable matter and appears thus as a conditional indicator.

Quality of different natural water sources

Rivers, lakes and other water courses are sources of the greatest significance for the industrial water supply. The quality of these sources is determined by the quantity and quality of the water that comes from underground and surface streams and from water coming from various industrial and communal establishments. Just as the quantity of surface water courses varies considerably during the year (periods of heavy rain, snow thawing, drought), the quality of river water also changes. Furthermore, the quality of the water changes along the course of the river, a matter of some significance in the case of long rivers which are joined by tributaries of varying quality.

River water usually does not contain large quantities of salts; the concentrations amount to approximately 500—600 mg/l. Rivers with greater concentrations are

generally to be found in the more arid regions. The most important solutes in river water are the cations Ca^{2+}, Mg^{2+}, Na^+ and the anions HCO_3^-, SO_4^{2-}, and Cl^-. Slightly mineralized river water contains in particular the ions Ca^{2+} and HCO_3^-.

With an increase in the total salt content in water, the concentration of the ions Na^+, SO_4^{2-} and Cl^- also increases. The concentration of the dissolved oxygen in water is close to the solubility limit at a given temperature.

The pH indicator for water usually does not leave the range 6.5–7.5. River water, as a rule, contains a certain quantity of suspended matter whose concentration varies considerably according to the season of the year and the amount of precipitation. In winter river water is characterized by higher concentration and hardness of the dissolved salts.

Ocean and sea waters usually have approximately the same concentration of cations and anions. The concentration of salt in the ocean and open seas is near 35 g/l, while in salty lakes it varies between 8 and 16 g/l. The most important solutes in sea water are sodium and chlorine ions. The total hardness of the oceans and open seas is about 215–225 meq/l, which includes bicarbonate hardness of approximately 15 meq/l. By properly selecting the location for the intake of sea water for industrial use it is possible to find water with a very small content of suspended matter. In summer, in some cases, the content of the matter suspended in sea water increases as a result of plankton development. In an untreated state sea water is used in the plants of the food-processing industry primarily for cooling purposes in the power units, while treated water is used for feeding the various evaporators. Sea water presents the special problem of being highly corrosive to most of the materials it touches.

Underground water is formed by the infiltration of atmospheric and surface water into the ground. In areas of water-bearing strata, infiltration turns into underground confluences whose character depends on the geological composition, relief, climate and other conditions. Underground water is distinguished by a greater variety of chemical composition. The degree of mineralization of underground water depends on the conditions under which the underground confluence is formed and varies between 100 mg/l and several grams per litre.

Equipment for supplying water to food-processing plants

The water-supply system consists mainly of water receivers for collecting water from natural sources and of pumping stations. The pumping stations are built near the receivers to supply the consumers through a system of pipelines. The receiver location is selected after careful tests, the purpose of which is to give information on the hydro-geological, hydro-chemical, and hydro-biological conditions that are best for the particular case. A good location for erecting a water receiver is in a bay or a calm place along a river bank, but the bay should be sufficiently deep to keep the possibility of sedimenting low.

One should avoid locating the receiver where the river bank is inclined. If a tributary or an island is near the collector it is necessary to determine the direction of the permanent tributary stream and the stability of the river bed. When selecting the location of a water collector the source of pollution of the water should be considered. If a river is unable in certain periods to supply the necessary quantity of water for the plant, provision should be made for seasonal or long-term regulation of

the river course. Alternatively a more suitable source of supply should be chosen. If the river lacks sufficient depth, it is necessary to regulate the river-bed. The normal water depth where the river swerves from the main course into the collectors should be at least 2.5 metres in summer and 3 metres in winter. The height of the water level determines the kind and size of the water collector. If the water is very turbid it is allowed to enter the collector only after most of the coarsely suspended matter has been drained off.

From the collector situated right beside the river course the water is transported by gravity through pipelines or concrete canals to the pumping station, from where it is pumped to the factory. These pipelines are usually laid in the earth all the way from the pumping station to the consumer to prevent water from freezing in winter.

With respect to their reliability and continuity of work, pumping stations can usually be divided into three kinds as follows:

(a) Pumping stations that are not allowed to stop operation because the disruption of complicated power and technological processes is not permissible.

(b) Pumping stations where brief stopping of pumps is allowed, for example, when it is necessary to switch on the other generator.

(c) Pumping stations where breaks during operation are allowed.

Pumping stations of the first and second kind should be set up to receive energy from two different sources, as for example, electric and steam power stations; in case one of the two fails, the other one can readily be switched on. The pumps at the pumping stations can be of various capacity, i.e. from several m^3 of water per hour up to several thousand m^3/h. The pressure drop which these pumps can handle ranges from several metres to several hundreds of metres of the water column. The capacity of the pumps is determined by the size and capacity of the factory. The pressure drop the pumps can handle depends on the height differential, the distance between the factory and the pumping stations, the diameter of the pipeline, friction loss and other conditions.

The types of installations (pipelines, fittings, measuring and control devices) and the materials from which they are made depend on the water quality required and on the pressure in the system. For example, in a system supplying potable water and water for technological application in the organic food-processing industries, iron, steel, asbestos-cement, concrete, ceramic or plastic pipelines may be used. Hydraulic calculations for the pumps and pipelines are based upon the technical and economic conditions, exploitation conditions, water quality, material hardness, etc.

WATER QUALITY FOR TECHNOLOGICAL AND OTHER USE IN INDIVIDUAL BRANCHES OF THE FOOD-PROCESSING INDUSTRY

Technological water that comes into contact with the products of the food-processing industry must meet the quality standards required for drinking water.

However, each particular branch of the industry imposes specific water quality requirements. The food-processing industry usually uses water that meets the waterworks standards of potable water. In places where it is not possible to utilize waterworks water either surface or underground natural water must be used, but it must be subjected to sanitary checks and treatment before entering the production process. Water treatment includes the following operations: clarification and decolourizing; elimination of corrosive gases, iron, oil, calcium and magnesium salts, and disinfection by means of various reagent and non-reagent methods. Disinfection of water (the removal of bacteria and micro-organisms) is achieved by chlorine, hypochlorite, chlorinated lime and the ions of silver and copper. Treatment with ultra-violet rays is also a highly efficient method.

Water for technological application

Water for the production of alcohol

The classification of water according to the degree of its suitability for the production of alcohol is given in table 3. The concentration of impurities in the water and their properties decisively influence the technological process of alcohol production.

The pH of the water influences the preparation of wort because of the better solubility of starch in alkaline water. The carbonates in concentration up to 300 mg/l scarcely influence the wort, but at higher concentrations they substantially lower the activity of diastase. The diastase of wort is activated by sulphuric acid salts such as $CaSO_4$, $MgSO_4$, and Na_2SO_4 if their concentration is close to 400 mg/l. On the other hand, alkaline water (water having pH higher than 7.5), slows down the hydrolysis of starch, particularly at somewhat elevated temperatures.

The chlorides, nitrates, phosphates and nitrites up to 200 mg/l and the presence of sulphuric acid and carbon dioxide, do not greatly influence malt diastase. The total concentration of the dissolved salts can reach a value even up to 3,000 mg/l without any special influence upon malt diastase. The hydrolysis is influenced by sulphates and chlorides. From 300–400 mg/l they raise the yield of the extract and the percentage of sugar. Nitrates and nitrites, phosphates and silicates (to 200 mg/l), ammonium (less than 20 mg/l), and NaCl concentration of 2–2.5 g/l have no substantial influence upon the hydrolysis.

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TABLE 3

CLASSIFICATION OF WATER SUITABILITY FOR THE PRODUCTION OF ALCOHOL

One litre of water contains (mg)

Classification of water	mg of O_2 for oxidation of organic matter in 1 litre of water	Dissolved matter	Calcium	Magnesium	Iron as Fe_2O_3	Sulphates	Chlorides	Nitrates	Nitrites	Ammonium	Total hardness in meq/l	Number of bacteria in 1 ml
Excellent	0	263	135	15	2	3	Trace	0	0	0	5.6	60
Very good	1.5	453	143	40	8	35	13	Trace	0*	0	7.1	750
Suitable	2.5	750	196	51	8	90	42	80	9	0	9.5	800
Applicable only in the utmost need	3.0	800	118	71	10	100	88	—	—	—	9.7	46,000

Bicarbonates of calcium, magnesium, and iron with a concentration up to 300 mg/l do not exercise any notable influence upon the fermentation process; in larger amounts they increase the quantity of the unfermented sugar and alcohol yield. At chlorine concentrations around 400–800 mg/l the percentage of unfermented sugar rises, but the alcohol yield does not decrease in the least. The highest concentration of sulphate that still does not influence the percentage of fermentation ranges somewhere from 400–800 mg/l.

An increase of the total salt concentration in the water of up to 2,000 mg/l favourably influences the fermentation process, but any further increase causes a deterioration.

Water for breweries and the production of soft drinks

The water used in the brewing of beer malt represents the basic component of beer and on its characteristics the quality of beer primarily depends. The water quality standards in brewing are even stricter than those for potable water. The water should not contain any suspended matter, mechanical impurities, or odours; nor should it contain large quantities of organic matter, micro-organisms, or iron or manganese compounds.

The salt composition of the water changes the acidity of wort and the brewery malt, thus influencing the biochemical processes of beer fermentation and the quality of the beer. The technological processes of beer production all take place in a weakly acidic medium because an alkaline medium has an unfavourable influence on the fermentation process. Hence water with a low content of potassium salts, carbonates in particular, and salts of sulphuric and hydrochloric acid is essential. An increase in the concentration of these salts spoils the flavour of beer.

Water hardness affects the colour of beer. To produce light beer of the Pilsen type, with a mild flavour and little bitterness, soft water is required because it has negligible alkalinity and very little gypsum. Hard water can also be used for producing light beer but only after preliminary softening and the reduction of alkalinity by means of lactic acid. To produce the Munich type of dark, weakly brewed beer with a sweet taste, water of medium hardness (5–5.5 meq/l) is best. Calcium and magnesium bicarbonates are the predominant salts in the water, and moderate amounts of gypsum are also present. Light ale having a high alcohol content and medium bitterness is obtained from the very hard water of Dortmund (15 meq/l), whose hardness is exclusively non-carbonate. For the production of dark beer with a bitter taste hard water can be utilized without any treatment, since dark malt has greater acidity and contains larger amounts of phosphates and amino acids that provide good buffering effect.

For soaking grains it is best to use natural water with a low content of chlorides and sulphates. Chlorides of calcium, magnesium and particularly sodium slow down the growth process; gypsum, which reacts with substances from grains, decreases their solubility. Besides, calcium salts form a diaphragm on the grain and obstruct the process of soaking. Iron and manganese in the water cause depositions of hydroxides of these metals on barley corn and also give it a dark colour. The influence of other salts on the malt quality has not yet been fully studied, but with an ordinary salt content in the water no great influence on the physiological processes occurring during corn soaking has been observed. This is because the hull of barley corn has the properties of a semi-permeable membrane, which allows water but not salts to enter the endosperm of the seed.

Table 4 gives the characteristics of the water used in the production of some of the world's outstanding brands of beer.

TABLE 4

WATER COMPOSITION FOR THE PRODUCTION OF SOME TYPES OF BEER

Quality indicator	Unit	Pilsen	Munich	Dortmund	Vienna
Dry residue	mg/l	51.2	284.2	1,110	947.8
Calcium oxide	mg/l	11.2	106	367	227.5
Magnesium oxide	mg/l	3.3	30	38	112.7
Chlorides	mg/l	5	2	107	39
Sulphates	mg/l	3.2	7.5	240.8	180.3
Nitrates	mg/l	Traces	Traces	Traces	Traces
Ammonium	mg/l	0	0	0	0
Total hardness	meq/l	0.57	5.3	15	14
Carbonate hardness	meq/l	0.45	5.1	6.1	11
Oxidizability (O_2)	mg/l	2	2	2	2
Iron compounds	mg/l	0.2–0.5	0.2–0.5	0.2–0.5	0.2–0.5
Manganese compounds	mg/l	Traces	Traces	Traces	Traces

Water properties are only one determinant of the quality of beer; the composition of the raw materials and the specific features of the production process are also important.

Table 5 lists the water consumption in the beer-producing concerns of Czechoslovakia.

TABLE 5

WATER CONSUMPTION IN BREWERIES OF CZECHOSLOVAKIA

Water consumption mode	Consumed litres of water per litre of beer produced
Seeds soaking in malt	7 – 8
Malt brewing including the washing of brewing equipment	2 – 2.5
Malt cooling	2 – 3
Rinsing of tanks and barrels	3 – 5
Cooling installation	10 – 15
Steam consumption:	
Steam-engines with counterpressure	1 – 2
Steam-engines with condensation	20 – 25
Total:	45 – 60

Considerable quantities of water are used for dissolving auxiliary chemicals and for washing the technological apparatus (soaking basins, wort-storage vessels, pipes, heating coils) and the filter presses. Large quantities of water are also consumed cooling malt in the spray coolers. The water used for washing remains on the walls of the containers and mixes with malt or the end-product. For this reason it must be free of bacteria, taste and odour.

It is most economical if the water used in a brewery for both production and power is purified in a single installation. Conventional methods of treatment are used, with certain additional operations to provide the quality desired for a particular type of beer.

Since the water used in the production of soft drinks must meet drinking water standards, it is usually taken from the municipal water system.

Water for the canning industry

The bulk of water in the canning industry is used for technological purposes (preparation of sauces, syrups, brines), the remainder for washing the vessels, etc. This water must meet all the standards for potable water.

The presence of magnesium chloride and an elevated water hardness with calcium and magnesium content higher than 40 mg/l are especially undesirable. In such water leguminous vegetables in particular (green peas, beans, horse-bean, etc.) and meat require longer cooking and acquire an unpleasant taste. The water should contain no substantial quantity of iron, especially if the canning of apples, pears, sour cherries or green peas is involved, since iron gives all products a very unpleasant brownish shade.

On the other hand for some operations, such as soaking cucumbers in brine, hard water is necessary. The cucumbers become hard and retain their natural colour. If the water is too alkaline the products soften and lose their shape; if it is too hard, raw materials become tough and are difficult to process. Hard water is unsuitable for the preparation of juices and syrups. The compounds of calcium and magnesium found in it cause tanning (hardening of fruit and vegetable shells, in particular of green peas and beans). As these compounds often occur in edible salt too, the use of purified salt with a maximum calcium content of 0.3 per cent is recommended in canning vegetables. Thus brine should be prepared with the lowest acceptable concentration of salt in order to minimize the effects of calcium and magnesium. This recommendation should also be heeded in the case of preserving meat products.

Using hard water for washing the raw materials prior to canning does not affect the quality of the final product.

The water composition necessary for this branch of the food-processing industry is given in table 6.

Water for bakeries

Bakeries require transparent, colourless water that is free of taste and odour. It should contain no organic matter whatsoever or yeasts and bacteria. The maximum allowable concentrations of certain other substances are: ammonium and nitric acid, traces; iron, 0.1 mg/l; manganese, 0.005 mg/l; and hardness, 7–10 meq/l. The other quality indicators should conform to those for potable water.

TABLE 6

CHARACTERISTICS OF THE WATER USED IN INDIVIDUAL BRANCHES OF THE FOOD-PROCESSING INDUSTRY

Quality indicator	Unit	Canning	Starch	Sugar	Dairy
Dry residue	mg/l	500	600	300–500	500–600
Calcium oxide	mg/l	120	120	200	200
Magnesium oxide	mg/l	30	20		Traces
$Fe_2O_3 + Al_2O_3$	mg/l	0	Up to 0.5	Traces	Up to 0.5
Chlorides	mg/l	30	60	50	30
Sulphates	mg/l	36	70	60	120
Nitrates	mg/l	Traces	0	Traces	Up to 15
Nitrites	mg/l		0	0	0
Alkalinity	mg/l	2.5–4.5	4–5	60	4.5–5.5
Oxidizability	mg/l	2	2.5	2.5	*2.5
Ammonium	mg/l	0	0	0	Traces
Hardness	meq/l	6–7	7	Up to 7.5	Up to 7.5

Water for the manufacture of starch and starch products

In the starch industry water of a hardness not greater than 7.5 meq/l is used. The water must be transparent, odourless and free of suspended matter. It should contain no fermentation agents. The brownish colouring of starch is caused by organic matter of animal origin, the yellow colouring by iron compounds. Hard water should not be used in this branch of the food-processing industry. Table 6 shows the required water quality.

Water for use in the sugar industry

The water used in sugar factories must be scrupulously clean, soft if possible, and without any foreign odours or taste. Only the least possible amount of sulphates, calcium salts, or alkaline salts is permitted in the water. Organic matter may cause difficulties by decomposing sugar when it is extracted from sugar-beets. For this reason water containing organic compounds is not suitable for rinsing the filter presses and filters or for slaking lime to be used in the process of sugar extraction. Sulphates produce a grey colour in sugar. Easily soluble alkaline salts pass largely into the mother liquor, increasing its quantity and raising the sediment quantity in raw sugar. Nitrites obstruct sugar crystallization. Iron and manganese in the water colour sugar. Table 6 gives the standards for the water to be used in the production of sugar.

Water in the dairy industry

In the production of butter, cheese and related products and in milk pasteurization, only impeccable water (colourless, odourless, with hardness not exceeding 7.5 meq/l) should be used. The water for rinsing butter should contain not more than 40 mg of magnesium per litre, since magnesium salts give a bitter taste to butter. Iron and manganese are allowed only in insignificant quantities (up to 0.05 mg/l), as they give dairy products a metallic taste and cause the decomposition of fats, thereby greatly lowering their quality.

Of all bacteria found in water, the *B. fluorescens* strain that decomposes fats is especially harmful to dairy products. It also causes cheese and milk to decompose, leaving a greenish-yellow crust with the very unpleasant odour of putrefaction. Table 6 presents the data for the water quality required in the dairy industry.

Water in slaughter-houses, meat and fish processing

The water used in these industries must be transparent, colourless and free of taste and odour. Its hardness should not exceed 7 meq/l and the concentration of calcium, which forms a hard crust on processed meat and fish products, must be the least possible. The concentration of iron must not range above 0.05 mg/l as it causes brownish colouring of the products. The edible salt ought not to contain more than 0.3 per cent of gypsum.

In the water used for washing raw meat, dirty fish and the apparatus used in these industries, the content of salt does not play an essential role. However, suspended matter, including organic, and bacteria causing fermentation must all be entirely removed.

Drinking water

In all branches of industry water for drinking must meet the basic requirement that it be harmless to man. Table 7 gives the standards for potable water from the water supply system and the standards of water quality after each operation in treating water for drinking.

Only in exceptional cases and with the consent of the sanitary authorities can turbidity of more than 3 mg/l, colouring exceeding 35°, or hardness above 14 meq/l be tolerated. If in natural water to be used for drinking these limits have been exceeded it must undergo softening treatment.

Water for thermo-power station equipment

In a thermo-power plant that is an integral part of a food-processing concern, water is used for feeding boilers, cooling condensers of steam turbines and heating. The impurities contained in raw water cause a whole series of undesirable processes in the installation: boiler scale formation on tubing and heating surfaces, deposits inside steam engines, turbines and pre-heaters, corrosion of boiler plating, steam ducts, heat exchangers, etc.

TABLE 7

DRINKING WATER QUALITY INDICATORS

Quality indicator	Unit	Parameter
(a) Waterworks drinking water		
Colouring (Pt - Co scale)	Grade	Above 20
Transparency (after Schrift)	cm	Up to 20
Total hardness	meq/l	Up to 7
Lead content (Pb)	mg/l	Up to 0.1
Arsenic content (As)	mg/l	Up to 0.05
Fluorine content (F)	mg/l	Up to 1.5
Copper content (Cu)	mg/l	Up to 3
Zinc content (Zn)	mg/l	Up to 5
Total number of bacteria at t = 37°C		Up to 120
(b) Drinking water treated separately after each particular operation		
Turbidity after purification	mg/l	Up to 2
Residual active chlorine after water disinfection	mg/l	0.3–0.5
Iron after deferrization	mg/l	Up to 0.3
Active reaction after purification and softening	pH	6.5–9.5

Water for steam-boiler systems

Boiler scale is a source of many difficulties in thermo-power plants. It has a far smaller coefficient of thermal conductivity than steel, and therefore the heat transmission is greatly reduced. The growing thickness of boiler scale on the steel plating causes loss of heat in the boiler system. Because of this the fuel consumption increases in order to maintain the required steam temperature. Table 8 gives the fuel consumption increase as dependent on the thickness of the layer of boiler scale.

One of the main reasons for the formation of sediments in boilers is the increase in concentration of dissolved substances as the boiler water evaporates. In this process the substances that reach the state of saturation first are the first to form as a sediment.

The various kinds of boiler scale depend on the salt composition of the raw water. If carbonate hardness is dominant in the water carbonate scale forms. If many sulphate salts are dissolved sulphate scale results, while a large amount of silicates in the raw water will produce silicate boiler scale. All these kinds of boiler scale differ from each other in hardness porosity and the characteristics with respect to heat transmission. Porous or laminated boiler scale and scale soaked with oil or containing large quantities of silicates are least able to conduct heat.

TABLE 8

AVERAGE FUEL CONSUMPTION INCREASE WITH THICKNESS OF BOILER SCALE

Layer thickness (mm)	Consumption increase (%)
0.5	1.0– 1.5
1.0	2.0– 3.0
2.0	4.0– 5.0
3.0	6.0– 7.0
4.0	7.0– 8.0
5.0	8.0– 9.0
6.0	9.0–10.0

Depositing scale on the boiler walls, boiler tubes, etc. causes deterioration of heat transfer from the pipes to the water. Overheating the tubes leads to the loss of hardness of the material, and this often leads to an explosion. Table 9 presents the coefficients of thermal conductivity for typical kinds of scale.

If the coefficient for steel is assumed to be 30 kcal/m h degC, then an even clearer picture of scale activity can be obtained.

TABLE 9

COEFFICIENT OF THERMAL CONDUCTIVITY FOR SOME TYPES OF SCALE

Scale type	kcal/m h degC	Structure and chemical composition
Oil greased scale	0.1	Contains much organic matter.
Silicate scale	0.07–0.2	Hard, settling on the thermally most stressed boiler surfaces; consists mainly of the deposit type $5CaO \cdot 5SiO \cdot H_2O$ and $CaSiO_3$.
Gypsum scale	0.2–2.0	Distinguished for great hardness and compactness. At low pressures it deposits in the form of $2CaSO_4 \cdot H_2O$ $CaSO_4 \cdot 2H_2O$ and at high pressures as $CaSO_4$.
Calcium carbonate minutely crystallized	0.2–1.0	In conditions of boiler water evaporation and with excess of Na_2CO_3 in it, $CaCO_3$ develops in the form of sludge and partially settles on the walls.
Calcium carbonate coarsely crystallized	0.5–5.0	When there is no water evaporation, deposition of $CaCO_3$ takes place in the form of solid crystallized scale on the walls of economizer and heater, and within the condenser and feed pipes.

As recommended by the Vereinigung der Grosskesselbesitzer im Bund Deutscher Technik (VGB), Federal Republic of Germany, the qualities of the feed and boiler water must not exceed the values given in tables 10 and 11.

TABLE 10

QUALITY STANDARDS FOR BOILER FEED-WATER (VGB)

Quality indicator	Feed-water for boiler with single phase circulation (Durchlaufkessel)	Feed-water for boilers with forced water circulation			
		20 atm	40 atm	60 atm	80 atm and more
General conditions	Pure and colourless				
Oxygen (mg/l)	Up to 0.03				
Hardness (meq/l)	In traces	0.02	0.01	0.01	In traces
Iron (mg/l)	Up to 0.02	If possible up to 0.05			Up to 0.03
Copper (mg/l)	Up to 0.005	Up to 0.01			Up to 0.005
Total CO_2 (mg/l)	Up to 1	If possible up to 20			Up to 1
pH at 20°C	7–9.5	7–9.5			7–9.5
Silicic acid (mg/l)	Permanently running up to 0.02	If there is no desludging, in permanent running maximum 0.3			
Oil (mg/l)	Up to 0.3	If possible up to 10.5			Up to 0.5

TABLE 11

QUALITY STANDARDS FOR BOILER WATER (VGB)

Pressure in atm. gauge	20	40	64	80	125	160
p-value (meq/l)	Up to 10	To 6	To 3	To 1	To 0.3	To 0.1
Silicic acid (mg/l)	Compute from p-value by formula (70 + 7.0)		To 10	To 4	To 1.2	To 0.4
Phosphates (mg/l)	Up to 25	To 10	To 10	To 3	To 3	To 3
Specific electro-conductivity ms/cm	To 8,000 D=0.4°Bé	To 5,000 D=0.25°Bé	To 2,500	To 1,500	To 250	To 50

According to the standards of the Union of Soviet Socialist Republics the steam-boiler water supply must ensure the smooth operation of boilers without any damage to the boiler elements caused by the deposition of scale, slurry, or metal corrosion. For every boiler with a capacity of 2 t/h or more standards of water and steam should exist. For boilers with a capacity below 2 t/h that are fed by untreated water or by a mixture of this water with a condensate or with softened water the boiler scale should be periodically removed from the heating surfaces.

Evaporators and heat exchangers in food-processing plants also have their corresponding water standards.

Water for cooling purposes

The food-processing and other industries use water-cooled heat exchangers, condensers and reactors. The temperature of the water in such cases is usually low, ranging within the limits of 50-60°C.

Cooling is effected by water flowing through the system. This water, after becoming hot, can be discharged into the sewer or recooled and recycled. The former procedure uses an open (flow-through) cooling system, and the latter a closed (recycled) one.

In the second case water is recycled into the cooling towers or into the spray towers where it is cooled to the initial temperature and then returned into the cooling cycle. The water utilized for cooling must not leave any deposits in the piping and apparatus. Scale deposition on the walls greatly decreases cooling efficiency by reducing the rate of heat transfer. The cooling water must not contain any coarse inorganic particles (sand) that could remain in the system. The softer, suspended matter (clay) as a rule does not settle, but its particles get trapped by the scale deposits and subsequently drop with them as an amorphous deposit on the heating surfaces and thus prevent good heat transfer.

Live organisms (bacteria, fungi) can develop in water that contains a large amount of organic matter when it is used for cooling in condensers at temperatures of 30-40°C. Various organisms can multiply and develop in sea water that is used for cooling. Deposition of scale and other solid sediments rarely occurs in a cooling system with wall temperatures between 30-40°C. In recycle systems the danger of deposit formation on the cooling surfaces increases with the loss of carbonic acid formed as a result of water heating and its spraying in the cooling towers. In this case the equilibrium of carbonic acid shifts to the right:

$$Ca^{2+} + 2HCO_3^- = CaCO_3 + CO_2 + H_2O$$

Another result is the formation of a poorly soluble deposit of calcium carbonate. The chances of deposit formation do not depend on the concentration of calcium bicarbonate alone. The process is also affected by the water heating intensity in the system, by the loss of carbonic acid during water spraying, by the presence of organic substances, and by the stability of the water.

Table 12 lists the water-cooling quality standards valid in the Soviet Union.

Water for fire fighting

When designing and erecting food-processing plants provision must be made for supplying water for fighting fires. Usually water for this purpose is taken from the

already existing water supply system. A certain number of fire-prevention pumps is set up at the very pumping station that supplies a particular factory with water This is called a "high pressure fire-combating water system".

In plants where the fire hazard is great, regulations in force in case of outdoor fire (buildings) call for spare water per square metre of the area of the factory, or in case of indoor fire (installation, machines, raw materials) per degree of danger depending on the kind of industrial production.

TABLE 12

QUALITY REQUIREMENTS FOR COOLING WATER

Quality indicator	Unit	Flow-through system	Recycle system
Total salt content	mg/l	Up to 3,000	Up to 3,000
Chlorine ions content	mg/l	Up to 1,000	Up to 1,000
Sulphate ions content	mg/l	—	Up to 400
Silicic acid content	mg/l	—	Up to 200
Gypsum content	mg/l	Up to 17.8	Up to 25.6
Carbonate hardness	meq/l	Up to 2.5	Up to 1.45
Water alkalinity	meq/l	—	Up to 15
Carbonate hardness at introduction of poli-phosphate into water	meq/l	Up to 5.35	Up to 5.35
pH	—	6.5–7.0	6.5–7.0

WATER-PURIFICATION METHODS

When raw water does not meet the standards required by the food-processing industry or does not come up to drinking water requirements it must be purified by the appropriate method.

For partial elimination of suspended matter and plankton, the water is subjected to microfiltration by means of mats or grids with apertures of 20 40 microns. Clarification is achieved by coagulation with subsequent settling and filtering. Decolourizing the water is effected by chlorine or ozone, or by special coagulation with additional filtration. The separation of suspended substances (clarification) and decolourizing are usually conducted simultaneously in the same equipment.

Odours and taste can be eliminated from raw water if the water is treated with chlorine or charcoal. The phenol odour can be removed by addition of ammonia and chlorine. Bacteria can be eliminated by treatment with chlorine, ultra-violet light and ozone.

Hard water is usually softened first by reagent methods (with lime) and if necessary also with the help of ion exchange resins.

Bivalent iron salts can be eliminated from water by oxidation with air. The precipitated iron hydroxide should be removed by filtration.

Silicic acid can be eliminated by demineralization or by means of magnesium compounds if the treated water is to be used for feeding medium and high pressure boilers.

Hydrogen sulphide is separated by water aeration or by chlorination and subsequent filtration.

To prevent corrosion and scale formation in the water-treatment system the water is stabilized by changing the pH or by adding sodium metaphosphate. To prevent the formation of biological deposits the water is chlorinated.

Clarification and decolourizing of water

Microfiltration of water

Microfiltration of water containing planktons increases the capacity of the water-preparation equipment by reducing the amount of pure water needed for rinsing the filter. In this way the consumption of the coagulent is reduced. Practically 100 per cent of zoo-plankton, 70 90 per cent of phyto-plankton and 25 per cent of finely dispersed turbidity is eliminated.

Table 13 lists the results of microfiltration for water containing phyto-planktons, bluish-green algae, microcystis and anabaena up to 3,270 organisms per 1 ml.

A microfilter is an apparatus that operates continuously and automatically. It consists of a drum with filter elements, canals for water collection and a system of discharge pipes for the filtered water. The water enters the drum through the intake tube and is discharged through coarse filters into the microfiltration chamber. The

filters consist of metal screens with square apertures 40 microns on a side. To arrest the phyto-plankton cells and the finest particles (turbidity) the microfiltering screens use 20-micron holes.

TABLE 13

MICROFILTRATION EFFECT PER TOTAL NUMBER OF CELLS

| Microfilter capacity in m^3/h	Average microfilter effect in per cent		
	maximum	minimum	average
40–75	86.4	46.5	72.1
60	91	75	83

Water coagulation

Suspended substances found in raw water can be eliminated by settling in reservoirs and basins, but in the majority of cases this method is not very effective because the finest suspension particles and colloids can be removed from the water only if their electrical charge is destroyed. Natural settling is therefore applied only when coarser particles need to be removed. To increase the effectiveness of water clarification and decolourizing, coagulation is practised. The coagulation agents used are: aluminium sulphate $(Al_2(SO_4)_3)$, iron sulphate $(FeSO_4)$ as well as iron chloride $(FeCl_3)$.

Colloidal systems are formed when a coagulant is introduced into the water. In the process of coagulation flocs are formed (active particles that absorb the suspended matter and sink with it as a sediment). Polivalent cations in the coagulant alter the electrical charge on the colloid and reduce its stability.

When introducing aluminium sulphate into the water, dissociation takes place:

$$Al_2(SO_4)_3 \longrightarrow 2Al^{3+} + 3SO_4^{2-}$$

Aluminium ions react chemically with ions present in the water and are partly absorbed by the colloidal and suspended particles. The surplus of aluminium sulphate undergoes hydrolysis, forming poorly soluble aluminium hydroxide:

$$Al^{3+} + SO_4^{2-} + H_2O \longrightarrow Al(OH)SO_4 + H^+$$

$$2Al^{3+} + SO_4^{2-} + 4H_2O \longrightarrow Al_2(OH)_4SO_4 + 4H^+$$
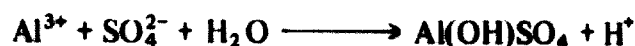
The resulting aluminium hydroxy sulphate carries a positive electrical charge that causes coagulation of negatively charged suspended particles. The hydrogen ions released by aluminium sulphate hydrolysis can obstruct or completely block the hydrolysis of the coagulant. Similarly, in coagulation of natural waters, hydrogen ions combine with bicarbonate ions, producing a molecule of water and a molecule of carbon dioxide which is released from the solution in the form of gas. When the concentration of bicarbonate ions in the water is insufficient to react with all the ions of hydrogen, it is essential to alkalinize the water with slaked lime, sodium hydroxide or sodium carbonate.

The coagulation should take place at optimum pH, which depends on the soluble salts in the water as shown in table 14.

TABLE 14

OPTIMUM VALUES OF pH FOR WATER COAGULATION BY $Al_2(SO_4)_3$

Water characteristics	pH
Treatment of soft water with alkalinity up to 1.5 meq/l	5.0–6.0
Treatment of medium hard water with alkalinity 3–4 meq/l	6.0–7.2
Treatment of hard, slightly turbid water with alkalinity over 6 meq/l	6.5–7.5

If ferrous sulphate is introduced as a coagulant into the water, hydrolysis takes place. The ferrous hydroxide oxidizes with oxygen in the water into ferric hydroxide, a coloidal substance.

For the normal course of ferrous hydroxide oxidation the pH of the water must be less than 8. To attain this pH the process of ferrous hydroxide oxidation is effected with a simultaneous introduction of slaked lime. Another way of accelerating the oxidation of bivalent iron (ferrous) into trivalent (ferric) is the simultaneous dosage of chlorine in the amounts of approximately 150 g per kilogram of commercial $FeSO_4$.

$$6FeSO_4 + 3Cl_2 \longrightarrow 2Fe_2(SO_4)_3 + 2FeCl_3$$

An important characteristic of water coagulation is that a reduction in the temperature of the coagulated water also reduces the hydrolysis rate of the coagulant.

The optimum dose of the coagulant for water of a particular composition is determined experimentally in each particular case.

Table 15 gives the approximate doses of anhydrous aluminium sulphate $Al_2(SO_4)_3$ for water clarification. The smaller doses are applied to water containing coarsely dispersed suspended substances—turbidity. If the water coagulation is effected by the solution of iron sulphate and chlorine, the dose listed in the table can be reduced 15–20 per cent. For the preliminary destruction of organic impurities that slow down the process of coagulation, 3–5 mg/l of chlorine as Cl_2 must be introduced into the raw water.

If it is necessary to deodorize the raw water before it enters the coagulation apparatus, activated carbon is added in doses of approximately 20 mg/l. If the water is deodorized after the coagulation process, i.e. before letting the water into the installation for further water treatment (decarbonization, ion exchange), this dose should not exceed approximately 5 mg/l.

TABLE 15

DOSAGE OF ANHYDROUS Al$_2$(SO$_4$)$_3$ FOR WATER CLARIFICATION

Water turbidity (mg/l)	Dose (mg/l)	Water turbidity (mg/l)	Dose (mg/l)
100	25–35	1,000	60 - 90
200	30–40	1,400	65 - 105
400	40–60	1,800	75 - 115
600	45–70	2,200	80 - 125

Water clarification and decolourization

Whether full or partial water clarification is carried out depends on the quality requirements. Complete water clarification is applied in industrial water supply systems when a suspended matter concentration of less than 2 mg/l (the upper limit for potable water) is required. Only such water can be used in the food-processing industry. For complete clarification and decolourization of water it is essential to coagulate the water with subsequent separation and filtration.

Water for which no quality standards are asked, i.e. where the upper limit for the concentration of suspended matter can be 50–100 mg/l, is used for industrial equipment, such as that used in cooling and heat transfer. In such instances even the water colouring does not have to be lowered below 4° on the platinum–cobalt scale.

Equipment for simultaneous water clarification and decolourization can be of the open type or pressurized.

In the open type the installation consists of a number of open elements, with the water level in each succeeding element lower than the previous one. The so-called "first-level pump" lifts water to the required level in the first reservoir, from which it flows by gravity through the whole clarifying installation until entering the reservoir for clarified and decolourized water. Here a "second-level pump" lifts it into a new reservoir from which it flows by gravity through the second part of the installation.

Figure 1 is a diagram of a big water-treatment station in which the water is fully clarified and decolourized, with the intake places of the reagent, coagulant and chlorine, indicated.

Figure 2 illustrates full water clarifying and decolourization by means of coagulants. Clarification takes place in the sedimentation reactors into which the water enters through the layer of settled sludge and filters. The contact of the coagulated water with the sediment layer made of coagulant and turbidity previously formed in the sedimentation reactor considerably speeds up the process of coagulation and leads to better clarification. The size of water-treating equipment of this type is substantially smaller than that shown in figure 1. Another advantage is that a chamber for the formation of hydrolyzed coagulant flocs is not needed.

In water clarification by coagulants (figure 2) the flow rate should not change by more than 15 per cent per hour nor the temperature of the feed-water by more than 1°C per hour.
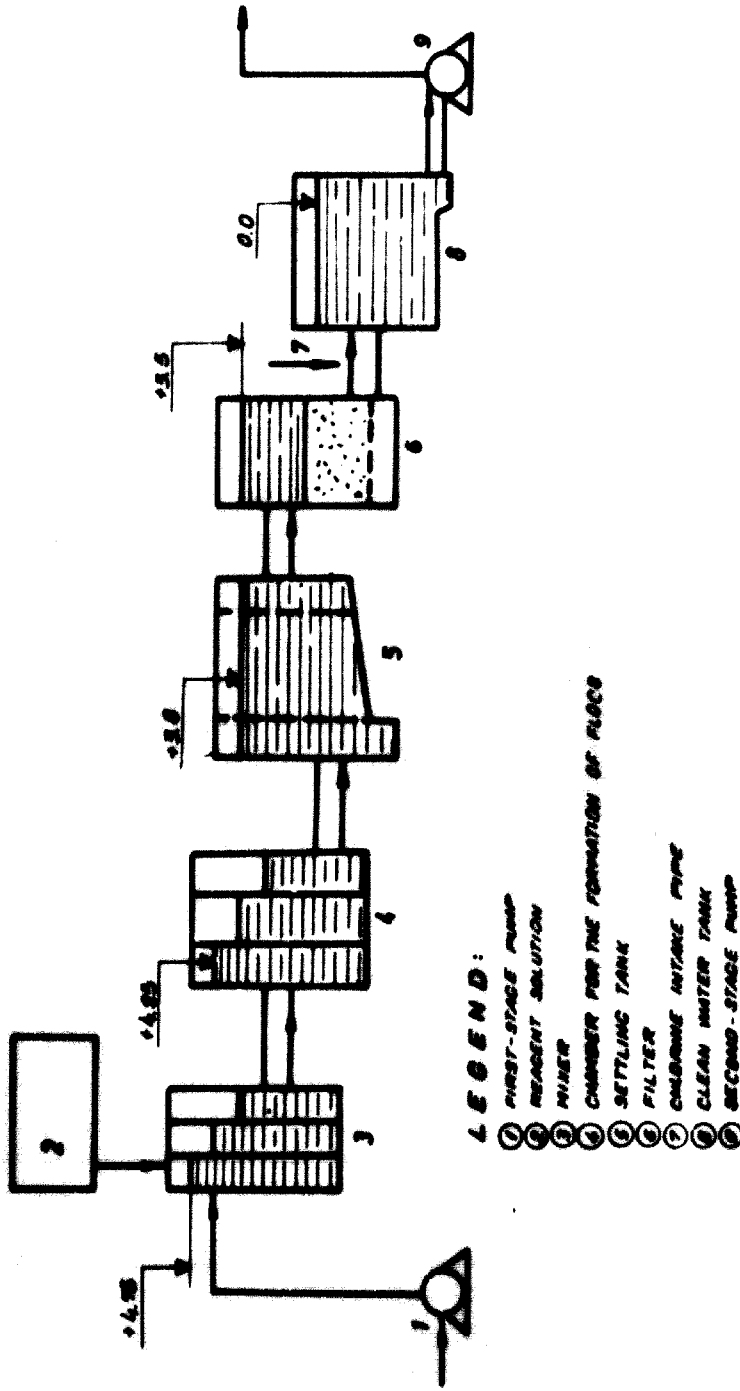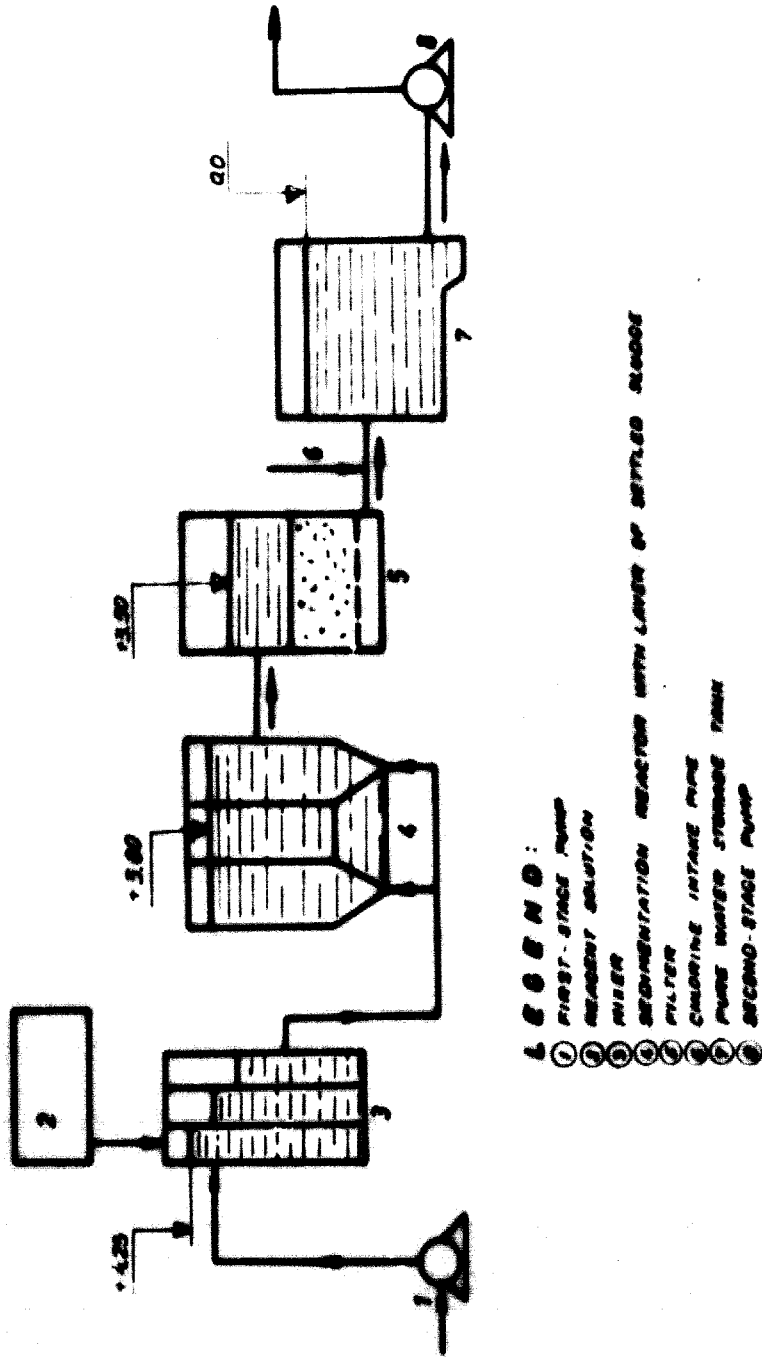
Figure 1. A water clarification and decolourization plant with a settling tank and a chamber for the formation of flocs, open-type principle.

LEGEND:

1. FIRST-STAGE PUMP
2. REAGENT SOLUTION
3. MIXER
4. CHAMBER FOR THE FORMATION OF FLOCS
5. SETTLING TANK
6. FILTER
7. CHLORINE INTAKE PIPE
8. CLEAN WATER TANK
9. SECOND-STAGE PUMP

Figure 2. A water clarification and decontamination plant with a sedimentation reactor operating on a two-stage principle.

LEGEND:

1. FIRST-STAGE PUMP
2. REAGENT SOLUTION
3. MIXER
4. SEDIMENTATION REACTOR WITH LAYER OF SETTLED SLUDGE
5. FILTER
6. CHLORINE INTAKE PIPE
7. PURE WATER STORAGE TANK
8. SECOND-STAGE PUMP

A so-called "contact sedimentation reactor" for water clarification also exists. Its significant feature is that it is able to clarify water having only a low content of turbidity (up to 150 mg/l). All the water-clarifying reactors mentioned operate only on the principle of water-flow rate adjustment, rendering the rate slower than that of the sedimentation flocs of the coagulant and the turbidity particles.

Sludge is periodically or continuously discharged when it reaches the density of 50,000 100,000 mg/l, i.e. when the demand for water that is discharged with sludge is not greater than 1.5 3.5 per cent of the total reactor capacity.

There are sedimentation thickeners which have a special rotary mechanism with blades. Slowly rotating, the blades collect the sediment, which becomes a very thick sludge on the bottom of the thickener. In that way the amount of water discharged with the sludge is very small. But these reactors also require special devices for driving and maintenance of the rotary elements that greatly complicate their manufacture and raise their price.

In open-type systems the height of the individual elements must be correctly established to compensate for the pressure drop inside the individual equipment units and the communication lines that link them. Thus, for the settling tank the pressure drop is 0.2 0.3 m column of water (m CW); for the sedimentation reactor with sludge layer 0.8–0.9 m CW; for the contact sedimentation reactor approximately 2.2 m CW; for the sand filter 2.5 3 m CW, etc.

If it is not possible to reach the necessary height differential between the individual elements of the open-type clarification equipment, a pressurized system should be used (figure 3). If instead of the filter-reactor (position 5) a conventional open reactor-sedimentation tank is used, then it too, must have a reservoir and also second-level pumps.

When determining the nominal capacity of either the open-type or pressurized system of water clarification plants, 5–10 per cent extra capacity must be allowed for water needed within the system for the sludge discharge from the sedimentation reactor, for rinsing the filter, reagent dissolution, etc.

Table 17 (p.33) lists tentatively basic data for water clarification and decolourization equipment.

All the pipelines and fittings for the coagulant solution must be made of acid-resistant materials; polyvinyl chloride, polyisobutylene, etc. Pipelines for the milk-of-lime supply to the sedimentation reactors to achieve the required pH must have a diameter larger than 25 mm, and a flow rate greater than 0.8 m/sec to avoid pipeline choking.

The reagent solutions are introduced in the following places: the coagulant into the pipes leading to the sedimentation reactor or directly into the reactor; milk of lime serving as the pH stabilizer directly into the sedimentation reactor; chlorine for killing the bacteria into the suction pipes behind the first-level pumps; and chlorine for the secondary chlorination after the filter, namely into the already clear water.

When the polyacrylamide solution is simultaneously fed into the coagulated water, the process of coagulation is noticeably speeded up. Polyacrylamide forms particles with some admixtures in water and with products of coagulant hydrolysis. These particles have a high specific gravity and therefore settle very quickly.

Settling tanks and sedimentation reactors with a sludge layer

Settling tanks and sedimentation reactors with a sludge layer are designed to remove the greater part of the suspended substances (turbidity) from raw water.

Thereafter the water flows into open or closed filters, which eliminate the remainder of the suspended matter. The water emerging from the settling tanks must not contain more than 30--40 mg/l of turbidity. Two types of settling tanks are in current use: the horizontal and the vertical. The horizontal type can operate with or without coagulation, the vertical only with a coagulant charge. As sedimentation reactors with a sludge layer have proved to be more effective than settling tanks, the latter are used only when the water treatment is conducted with variable water temperatures. Figure 4 gives a schematic presentation of a horizontal and a vertical settling tank.
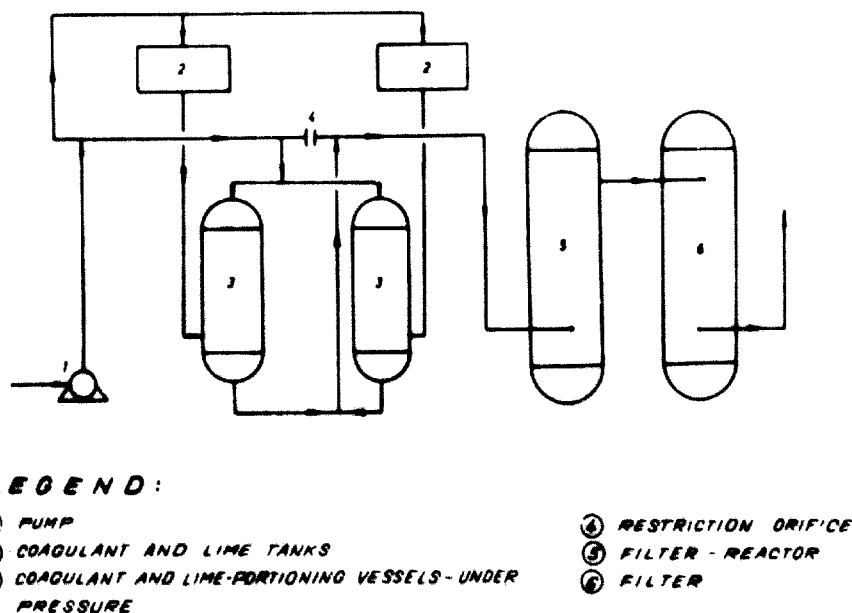

LEGEND:

① PUMP
② COAGULANT AND LIME TANKS
③ COAGULANT AND LIME-PORTIONING VESSELS - UNDER
   PRESSURE

④ RESTRICTION ORIFICE
⑤ FILTER - REACTOR
⑥ FILTER

Figure 3. A pressurized water clarification and decolourization plant

The fundamental difference between settling tanks and sedimentation reactors with a sludge layer is that in the latter case water passes through a layer of already formed sludge. Here the new flocs join those previously formed, bringing the coagulation process rapidly to an end with good water clarification. In the normal operation of the sedimentation reactor it is important for the deposit formed always to be in vibration so that the newly formed deposit particles may move easily through previously formed sludge. Passing through it they become larger and remain in the sludge. Because the sludge is formed in this way it is important that no sudden changes in temperature and equipment capacity occur. Furthermore, the water should not contain any air bubbles. To remove air bubbles the sedimentation reactor has a so-called "air-separation chamber" in which the water flow rate is 0.05 m/sec as compared to the flow rate of 0.75--1 m/sec in the inlet piping.

Figure 5 shows the "corridor type" sedimentation reactor. This type of sedimentation reactor consists of two side sections and a central one which represents the sludge-concentration zone. The water under treatment enters the operating sections (left and right) through perforated tubes (1) located at the reactor bottom. Channels (2) collect the clarified water, which is then sent through pipes (4) to the filter. The clarified upper water layer leaves the central sludge-concentration zone, passes through the perforated pipes (5) with a control valve (6) and enters the

collector (3). By discharging the clarified water into the collector (3) the sludge is enabled to flow from the operating sections through the hole (7) into the central section. The thickened sludge is continuously or periodically discharged through the perforated pipes (8).

(a) Horizontal
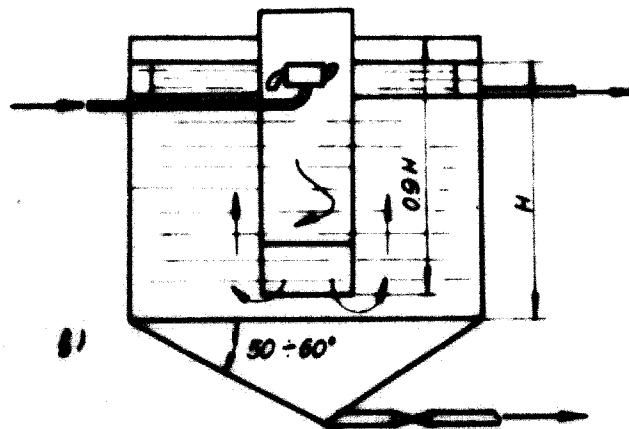

a)

(b) Vertical

b)
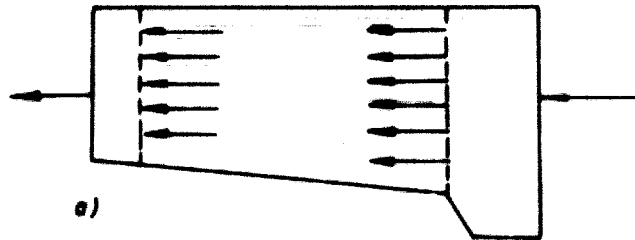
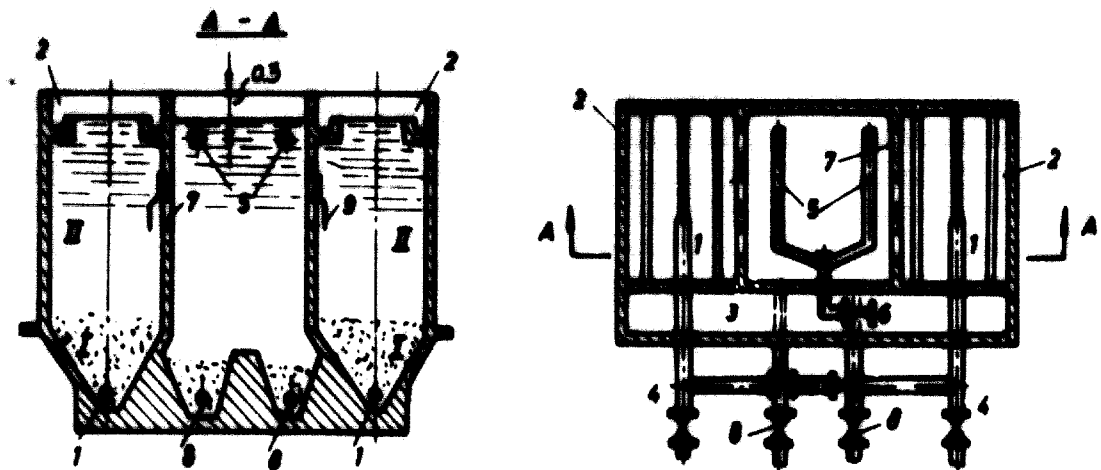*Figure 4.   Schematic presentation of a settling tank*

Figure 5.   "Corridor" type sedimentation tank

Table 16 gives data for the water discharge rate from the clarification zone above the sludge layer. If instead of aluminium sulphate, to which the table data refer, ferric chloride is used, then rates of 10 to 15 per cent higher can be allowed.

TABLE 16

WATER DISCHARGE RATE FROM THE SEDIMENTATION REACTOR

Suspended matter content in the raw water (mg/l)	Water discharge rate (mm/sec) winter season	summer season
Up to 100	0.7 0.8	0.9 1.0
100 400	0.8 1.0	1.0 1.1
400 1,000	1.0 1.1	1.1 1.2
1,000 2,500	1.1 1.2	1.1 1.2

The area of the sludge-concentration zone is chosen for the greatest water volume and turbidity that can be expected. The area of the total reactor should not exceed 1,500 m^2 and the height of the sludge-concentration zone about 1 2.5 m. The height of the water-clarification zone ranges from 1.5 1.75 m.

Some sedimentation reactors are differently designed. For example, a cylindrically shaped reactor with a conical bottom part as a sludge thickener needs no separate sludge sedimentation or water-clarification section. In comparison to the "corridor type" reactors they have a smaller surface for the same output, which means that they allow a faster movement of the water upwards. In both cases the water is fed into the lower part of the reactor and then moves upward at a definite rate, while the sludge particles sink into the lower part of the reactor. "Corridor type" reactors are used only when water clarification and decolourization is effected by coagulation, while the cylindrical type is used for simultaneous clarification and decarbonization, a topic to be discussed later. The sediment of the simultaneous coagulation and decarbonization process has greater specific gravity because the $CaCO_3$ and $Mg(OH)_2$ sludge is the result of decarbonization. Because the sludge thus formed is denser a higher water motion can be allowed in this kind of reactor.

Water filtration

In the water leaving the settling tanks or the sedimentation reactors 8 15 mg/l of suspended matter still remain. But to obtain the quality required for potable water, technological purposes, and the water for the steam-boiler feed, this water must still be filtered.

Filters can also be used for the partial clarification of water with turbidity up to 300 mg/l. They may be fast or slow. Fast filters can operate with a flow rate of 5 15 m/h, slow ones with a rate of only 3 5 m/h. In design the fast filters are usually of the pressurized closed type, while the slow ones are of the open type. They consist of a cylindrical vessel with layers of quartz sand as filtering media and a drainage system at the bottom. The water to be filtered enters at the top, disperses, falls evenly on the sand layer, passes through it and leaves the particles of suspended matter on it; through the drainage system it is then discharged into the reservoir of filtrated water.

Inevitably a cake of sludge forms that reduces the free cross-section between the pores in the filtration materials and offers increased resistance to the water being filtered. When the inlet and outlet pressure gauges indicate an excess differential pressure it is then necessary to clean the filter bed. In continuous filtration it is necessary to use a spare filter while cleaning the contaminated one. The cleaning of the filter media is accomplished by a preliminary air scour followed by an upflow of clean water. Rinsing water can be obtained by using an elevated wash-water storage tank, or a ground-level one with a pump, or from the pressure filter main, where a battery of four or more filters are employed.

The sand grains range in size from 0.7 to 1.5 mm. The total height of the filter bed varies from 0.7 to 2 m, depending on operating conditions. The drainage system carries a supporting graded gravel layer with a grain size of 2-4 mm, on top of which rests the filtering media layer. Recently the so-called "double-layer filters" have been gaining in popularity. The 0.4 to 0.5 m top layer is made of ground anthracite coal grains of 0.5-1.2 mm and the bottom layer of equal height is made of sand. The impurities in the water are arrested along the depth of the first layer; this is not the case with the one-layer filters. The water filtration results attained by two-stage filters are 2-2.5 times better than those obtained by the one-layer filters. Coarse-grained filters whose charge consists of sand with grain diameter of 1-2.5 mm with a layer height of up to 3 m are also in use. Filters under pressure have a limited use (for 25-50 mg/l 50-100 m/h). These filters are not manufactured serially and are used only in specially automatically controlled water-treatment plants.

Figure 6 illustrates the structure of a one-layer vertical filter operating under a pressure of 6 atm. The steel cylinder of this filter is welded to the spherically shaped bottom. The inlet pipe (1) with a funnel (2) for water feed and dispersion over the whole surface of the filter and the air-escape pipe (3) are in the upper part. The cylinder cover has a hole (4) for checking, overhaul and levelling of the filtration materials (9), which are placed on the drilled steel plate (7). The bottom of the filter has a thick concrete lining (5) on top of which the drainage system with filtered water outlet is located (6). An air-distribution device under pressure (8) loosens the sand particles prior to the rinsing operation from the bottom up (10). For washing out the filter the flow is reversed, and the wash water passes out through the wash water outlet (11).

Sand filters under pressure are manufactured with a diameter up to 3,000 mm and capacities up to approximately 70 m³/h.

Table 17 lists tentatively the basic data for water filtration equipment.

The operating cycle of the filter between the two rinsings must not be shorter than eight hours. However, in periods of heavy rains and snow thawing, with very turbid water, this cycle can be reduced to six hours.

Water disinfection

Water is treated with oxidants (chlorine, ozone), bactericides, ultra-violet light or ultrasonic waves to destroy microbes and bacteria. The most commonly used method in industry today is chlorination.

In chlorination two kinds of chlorine residuals may be used. The first, chloramine, or combined chlorine residual, is defined as chlorine in water in chemical
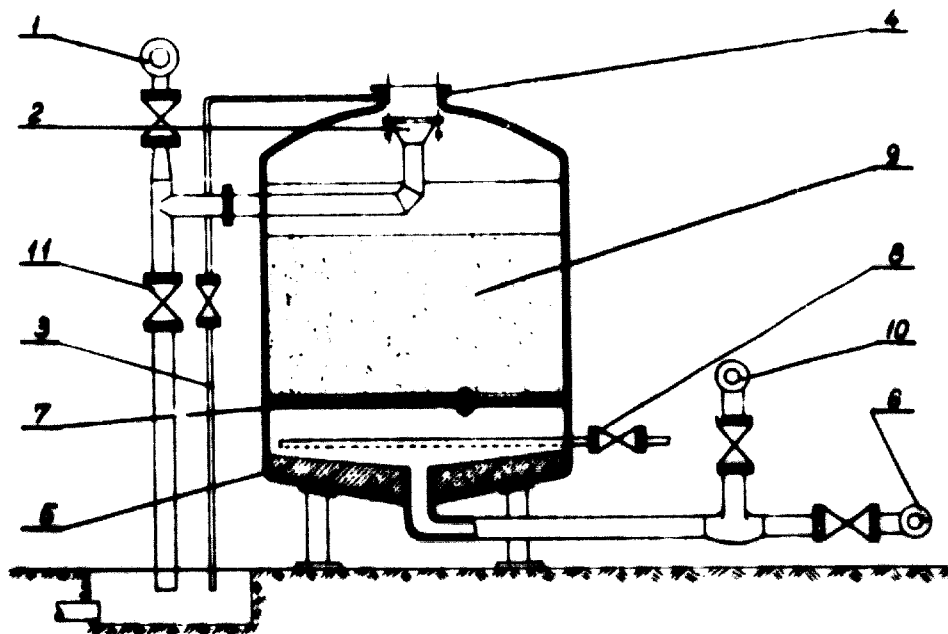
LEGEND:

1. RAW WATER INLET
2. FUNNEL
3. AIR - ESCAPE PIPE
4. HAND - HOLE
5. CONCRETE - LINED BOTTOM

6. DRAINAGE SYSTEM WITH FILTERED WATER OUTLET
7. DRILLED STEEL PLATE
8. AIR DISTRIBUTION
9. FILTER MEDIA
10. WASH - WATER INLET

11. WASH - WATER OUTLET

Figure 6. Sand filter for water clarification operating under pressure

TABLE 17

TENTATIVE DATA FOR WATER CLARIFICATION AND FILTRATION EQUIPMENT

| Basic equipment | Usage conditions for water quality indicator | | Plant capacity (m^3/h) |
	Suspended matter (mg/l)	Colouration (degree)	
Contact reactors	Up to 150	Up to 150	As desired
Sedimentation filters under pressure	Up to 50	Up to 70	Up to 125
Sedimenting reactors with sludge layer and filters	100–2,500	Up to 150	85–2,100
Water treatment without coagulation			
Slow filters	Up to 50	Up to 50	Up to 45

Table 17 (continued)

Basic equipment	Usage conditions for water quality indicator		
	Suspended matter (mg/l)	Colouration (degree)	Plant capacity (m³/h)
Preliminary filters and slow filters	50–250	Up to 50	Up to 45
Settling tanks and slow filters	250–500	Up to 50	Up to 45

Table 18 gives a survey of granulometric composition of the filter charge and the charge height.

TABLE 18

GRANULOMETRIC COMPOSITION OF THE FILTER CHARGE

Filter type	Grain diameter (mm)			Sand layer height (mm)
	min.	max.	mean	
Monobed filters with	0.5	1.2	0.7–0.8	700
quartz sand	0.7	1.5	0.9–1.0	1,200–1,300
	0.9	1.8	1.1–1.2	1,800–2,000
	Quartz sand			
Two-bed filter	0.5	1.2	0.8	400–500
	Anthracite			
	0.8	1.8	1.1	400–500

combination with ammonia or organic nitrogen compounds. The second, a free chlorine residual, is that residual chlorine existing in water as hypochlorous acid and hypochlorite ion. The tentative dose of chlorine for destroying the bacteria in filtered water is 0.75–2 mg/l. In normal chlorination of drinking water the content of the residual chlorine 30 minutes after the initial dosage must not affect the taste of the water but should not be below 0.1 mg/l. The dose of chlorine in the preliminary treatment of water having an elevated content of organic matter is 3–5 mg/l or more. The so-called "secondary water chlorination" with an initial dose of up to 20 mg/l eliminates taste and odour and purifies the polluted water. The residual dose of chlorine in this case should be 1–10 mg/l. In subsequent dechlorination the water is treated with either sodium sulphite (Na_2SO_3) or sulphur dioxide (SO_2).

Water can be chlorinated not only with gaseous chlorine but also with chlorinated lime ($CaOCl_2$). Dosage with the latter is easier and is manipulated on the principle of milk-of-lime or coagulant solution dosage.

Figure 7 shows chlorination for capacities of up to 125 m³/l. The chlorination plant consists of a dissolution tank (A), two solution reservoirs (B), and a dosage vessel (C). For small capacities these vessels are made of wood, for larger ones of concrete.

In vessel (A) the solution of chlorinated lime is prepared; from here it flows under gravity into vessel (B) where it is diluted to a specified concentration. Next it is led into the dosage vessel (C), whose volume should be at least one tenth that of (B), and from here it is discharged into the raw water either by pumps or through a diaphragm under pressure.
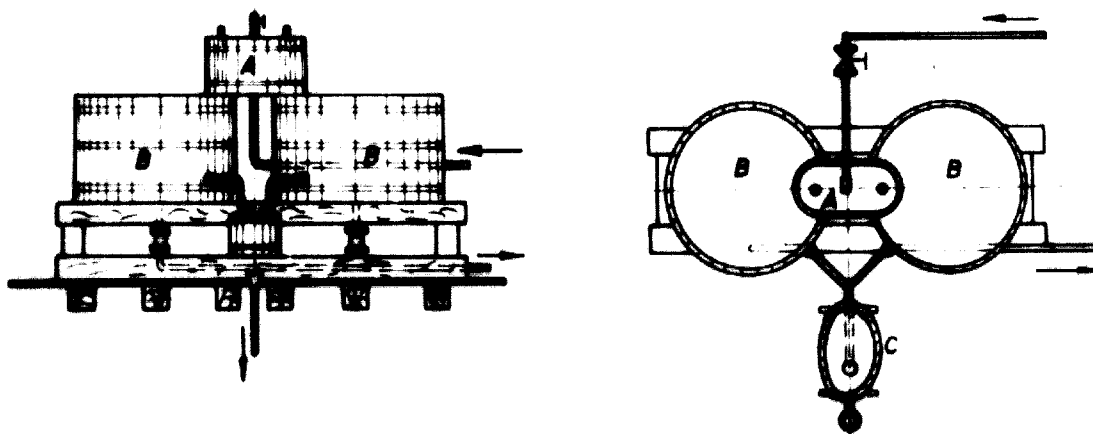

Figure 7. Typical view of a plant for water disinfection by chlorinated lime

Removal of iron from water

Today water quality standards are very strict with respect to the iron content, regardless of the use to which the water is to be put. The elimination of iron from water can be performed by aeration, coagulation, lime treatment, or by ion exchange. The essence of the aeration process and lime treatment lies in the transformation of bivalent iron into trivalent and its transformation into ferric hydroxide, which drops to the bottom. The most widely used method of extracting iron from underground water is aeration; from surface water, coagulation. Lime treatment combined with the ion exchange method is considered when it is essential not only to eliminate iron but also to soften water.

The removal of bivalent iron salts by aeration is effected in two stages. First, the ferrous hydroxide is obtained by the hydrolysis of the bivalent salt, and second, a deposit of ferric hydroxide is formed by oxidation with air.

When unstable ferrous bicarbonate is present in the water, the reactions of the removal are as follows:

$$Fe(HCO_3)_2 + 2H_2O = Fe(OH)_2 + 2H_2CO_3$$

$$H_2CO_3 = H_2O + CO_2$$

$$4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$$
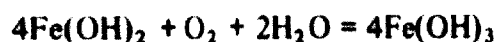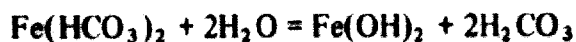
Besides saturating the water with oxygen, aeration releases CO_2 from the water. By reducing the pH the effect of the water aeration is slowed down.

The unit for removal of ferrous bicarbonate by aeration consists of: *(a)* a special apparatus for ensuring the oxidation of iron and the release of CO_2; *(b)* contact tanks where the oxidation process is brought to an end; and *(c)* sand filters that are used to remove sludge caused by iron oxidation.

If the iron in the water is in the form of sulphate, lime treatment is used. The lime reacts in the water with bivalent iron:

$$FeSO_4 + Ca(OH)_2 = CaSO_4 + Fe(OH)_2$$
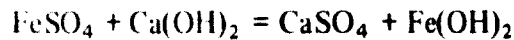
This is further oxidized by the oxygen in the water into trivalent iron.

If the iron in the water is in a colloidal form, the water also contains considerable quantities of finely dispersed turbidity and complex organic compounds. In this case the water is treated by coagulation, which is carried out in the same way as coagulation for clarification and decolourization.

Aluminium sulphate, ferric chloride or perhaps best of all, a mixture of the two are used as the coagulant. The optimum pH for this coagulation is 5.7–7.5.

Removal of oil from water

The removal of oil from water is now generally carried out by mechanical methods. Here and there adsorption methods using active carbon are applied, especially when the oil content in the water is very low (5–10 mg/l). At a higher oil concentration (above 10 mg/l) basins for oil separation (mechanical method) are used. In these separators the water is retained for a certain time to enable the separation of oil, which collects at the water surface because of its lower specific gravity. The oil is drained off from the upper layer, and the water is discharged from the bottom. The air intake in such separators increases the speed of the separation.

Recently in special cases centrifugal separators have been used to remove oil from water, but this is very costly.

Active carbon filters 1,000–2,000 mm in thickness can absorb oil in amounts up to 10 per cent of their own weight. The water flow rate through such filters is 5–6 m/h.

Water softening

Water softening is the process by which calcium and magnesium ions, which constitute the water hardness, are removed. Several methods exist; the most frequently used is the ion-exchange method, often preceded by preliminary water treatment with reagents. Scale deposition in low and medium pressure steam-boilers is prevented by the electromagnetic treatment of the feed-water. The crystal structure of scale-building salts is thereby destroyed and they are transformed into the amorphous state.

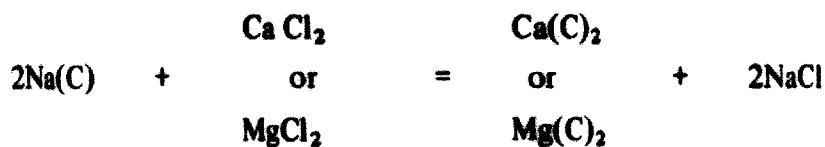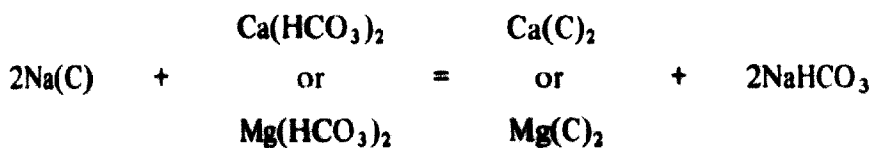#### Ion exchange water-softening method

Ion exchange resins are synthetic polymers that react with ions in diluted solutions. According to whether anions or cations are exchanged between resin and water, they are called anionic or cationic exchange resins.

The nature of the exchangable ions associated with the ion exchange resin is determined, in general, by the user. If, for example, an ion exchange resin is desired that will exchange sodium ions for some other cation in the water, the exchanger is first treated with a reasonably concentrated solution containing sodium ions, usually sodium chloride. Such treatment is known as regeneration.

Perhaps the most common and least tolerable chemical impurities in water are the hardness-producing ions, calcium and magnesium. They are responsible for the scale that deposits in boilers, pipes, condenser jackets, circulating systems, cooking utensils, and other equipment in contact with hot water. The presence of calcium and magnesium salts also adversely affects the taste of many food products.

If hard water is passed through the monobed ion exchange filter, cations Ca^{2+} and Mg^{2+} are replaced by the cations Na^+ or H^+ from the ion exchange resin, whereby the water hardness can be cut by 0.01–0.02 meq/l. The softening ability of the cation exchanger gradually declines in the process but can be restored by passing common salt or hydrochloric acid through the cation exchanger.

When water passes through the monobed of sodium cation exchanger, the following reactions take place:

$$2Na(C) \; + \; \begin{array}{c} Ca(HCO_3)_2 \\ or \\ Mg(HCO_3)_2 \end{array} \; = \; \begin{array}{c} Ca(C)_2 \\ or \\ Mg(C)_2 \end{array} \; + \; 2NaHCO_3$$

$$2Na(C) \; + \; \begin{array}{c} Ca\,Cl_2 \\ or \\ MgCl_2 \end{array} \; = \; \begin{array}{c} Ca(C)_2 \\ or \\ Mg(C)_2 \end{array} \; + \; 2NaCl$$

$$2Na(C) \; + \; \begin{array}{c} CaSO_4 \\ or \\ MgSO_4 \end{array} \; = \; \begin{array}{c} Ca(C)_2 \\ or \\ Mg(C)_2 \end{array} \; + \; Na_2SO_4$$

The symbol (C) denotes the cation exchange resin. As a result of sodium cation exchange the equivalent amounts of sodium salts appear, making the water more alkaline. Heating such water causes the partial decomposition of the bicarbonates into carbonates and, subsequently, into the corresponding hydroxides.

If water is filtered through a hydrogen (H) cation exchanger the previous equations will have, instead of sodium bicarbonate salts, chloride and sulphate, the corresponding free acids (carbonic, hydrochloric and sulphuric). The presence of these acids in the softened water after the H cation exchange causes the reduction of the pH of the softened water.

By treating a portion of the raw water with the sodium form of the cation exchanger and blending the effluent with that from the hydrogen form of cation exchanger, completely softened water of any degree of alkalinity may be obtained. The method is particularly suitable for raw water of high hardness, sulphate and

chloride content. There are several world producers that deal in synthetic ion exchange resins, such as Levatit and Permutit in the Federal Republic of Germany, Warion in Hungary, Ionac and Amberlite in the United States, etc. All these resins can operate at a water temperature of $80°$ C at the most. They come shaped as small balls of 0.5—1.0 mm in diameter with specific gravity of 0.8—0.95 g/cm^3. The water to be softened should have a turbidity less than 5—8 mg/l, and it should be free of colloids.

The exchange capacity of a particular ion exchange resin is expressed in gram-equivalent of the retained cations per m^3 of the cation exchanger that is in the scattered state.

The water-softening unit generally consists of one or more filters filled with the corresponding ion exchange resin (ion exchangers).

In addition to the ion exchangers, the water-softening plant should include the regeneration, storage and dissolution system, and the dosage unit. If it is a question of a Na cation exchanger, the NaCl solution is prepared in a separate container linked to the filter by pipelines. The solution is forced into the filter under pressure. If HCl or H_2SO_4 is used as a regenerant, the transfer of the prepared solution will require acid-resistant pumps or ejectors, specially insulated tanks and rubber pipelines. The H cation exchanger itself will have to be rubber-insulated and acid-proof.

The resin is regenerated when the first traces of hardness appear in the effluent from the ion exchanger. The ion exchange resin is first scattered by backwashing. Then an 8—10 per cent solution of NaCl or HCl (depending whether Na or H cation exchange is involved) is passed through. Finally, the mass is well rinsed of salts or acids from the top downwards.

The cation ion exchangers can be of an open or closed type, the latter being under pressure. Like the sand filters, they are supplied with fittings, water inlet and outlet couplings, the regenerant inlet, and the discharge duct. They are also equipped with a manhole and a control opening.

Table 19 gives the characteristic sizes of a series of cation exchangers.

TABLE 19

CHARACTERISTIC SIZES FOR Na CATION EXCHANGER FILTERS

External diameter (mm)	Column height (mm)	Filter cross-section area (m²)	Water and resin weight (t)
1,000	2,200	0.78	4.4
1,000	3,400	0.78	6.2
1,500	2,200	1.77	9.4
1,500	3,400	1.77	13.2
2,000	2,800	3.14	19.2
2,000	4,000	3.14	25.5

Figure 8 gives a drawing of a cation filter operating under pressure of maximum value 6 atm. When designing the filter, care should be taken to ensure correct rates of filtration (from 10–35 m/h). If the flow rates are below 5 m/h the water is not in contact with the whole resin mass but only the parts forming canals and autonomous passages; thus the resin bed is inefficiently exploited. Flow rates higher than 40 m/h cause an excessive overloading of the exchange resin, again obstructing its full utilization.

LEGEND:
1. WATER FEED
2. WATER OUTLET FUNNEL
3. BOTTOM WITH NOZZLES
4. SOFT WATER OUTLET
5. BACK WASHING WATER
6. REGENERATION SOLUTION
7. REGENERATION SOLUTION DISTRIBUTOR
8. DISCHARGE INTO CANAL
9. DISCHARGE INTO CANAL
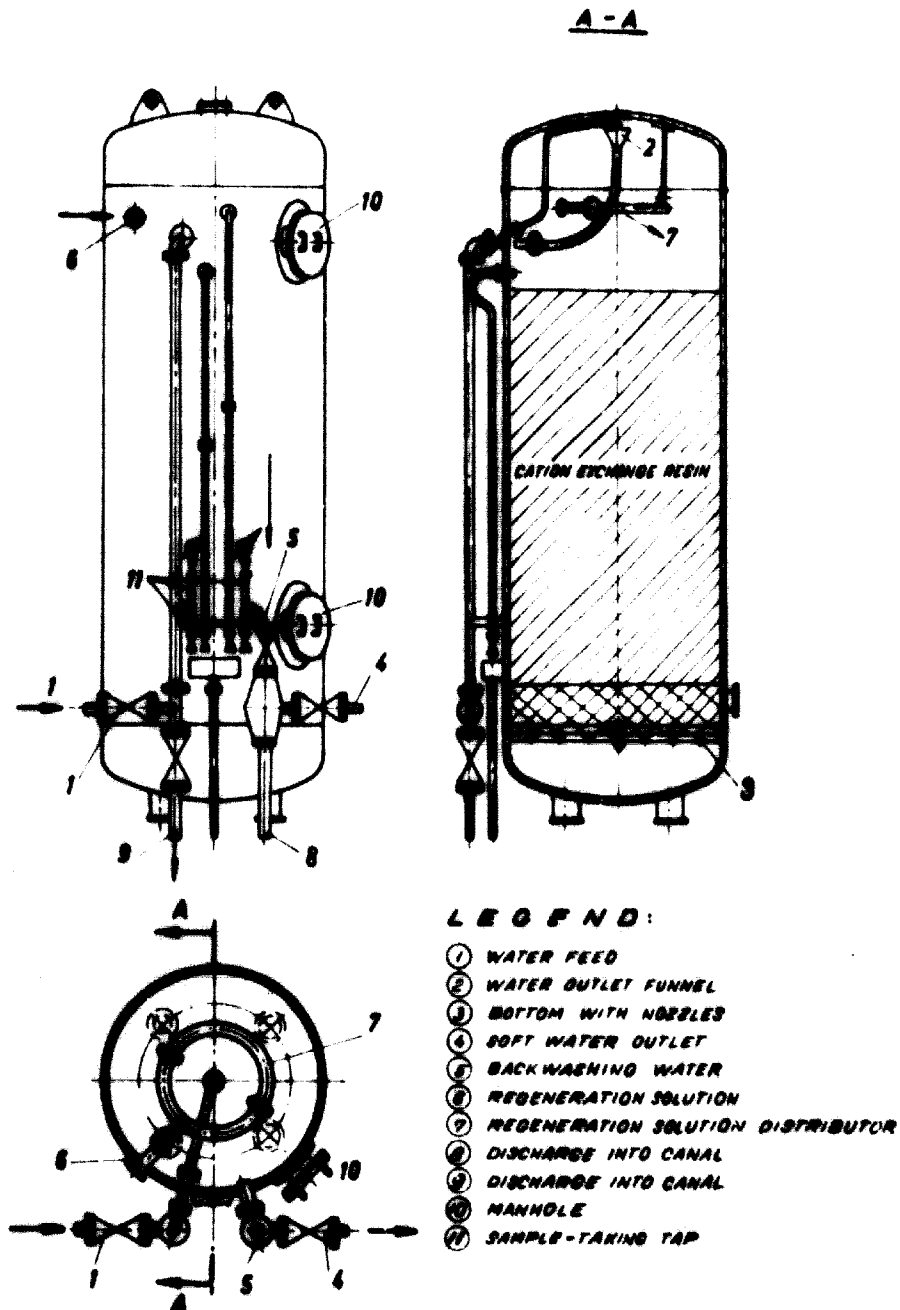10. MANHOLE
11. SAMPLE-TAKING TAP

Figure 8.   Cation exchanger operating under pressure

Figure 9 illustrates a water-softening plant using a parallel method with Na-H cation exchange.

Plants in which not only softening but also removal of all salts is effected (so-called demineralization plants) have anion exchanger filter units that are capable of exchanging CO_2, SiO_3 and all the anions from the water. These plants feed only boilers under very high pressure, as in thermal power stations.

Reagent methods for softening water

Hard water may be softened by active agents whose anions form with the cations of calcium and magnesium poorly soluble compounds such as $CaCO_3$, $Mg(OH)_2$, $Ca_3(PO_4)_2$ and $Mg(PO_4)_2$. These substances are then separated as deposits by specially suitable units.

Fine particles that have not settled in this unit are eliminated from the water by a sand filter. The removal of calcium and magnesium ions from the water is effected by calcium hydroxide and soda ash (Na_2CO_3) and is called lime-soda softening.

Plants employing this principle of water softening are capable of operating at ambient temperatures, when they are referred to as "cold process plants", or at temperatures approaching $100°C$, when they are identified as "hot process plants".

The lime-soda process, which converts calcium and magnesium salts in the raw water into insoluble solids, requires:

(a) Correct proportioning of the chemical reagents and raw water.

(b) Promoting the chemical reactions which precipitate the salts. This requires a suitable combination of coagulation, sedimentation, heat or sludge contact.

(c) Filtration of the chemically softened water to remove any traces of turbidity.

Since complete water softening cannot be achieved by the reagent method alone, this method is combined with the ion exchange method. The water is first softened with lime to eliminate the bicarbonate hardness; then the permanent hardness is removed by ion exchangers.

The elimination of bicarbonate is called decarbonization. This can be accomplished simultaneously with coagulation when the raw water is turbid, but in the case of clear water it is effected in a special decarbonization unit. In the process of parallel decarbonization and coagulation about 30–40 per cent of the silicic acid is eliminated. Decarbonization can be considerably speeded up by heating the water to 30–40°C. Without heating, reagent-softened water is usually unstable and likely to deposit the products of the uncompleted reactions on the piping. Since organic impurities and turbidities in the raw water slow down the process of softening, resort is taken to coagulation or preliminary chlorination. The lime dosage in the water-softening process depends on the ratio of magnesium and calcium ions and the bicarbonate ions.

When underground or clean surface water (with not more than 10 mg/l of suspended matter) is to be softened by lime, the so-called "fast reactor" is used, with subsequent filtration of the softened water in the sand filters. Fast reactors can be used when the calcium hardness substantially exceeds the magnesium or carbonate hardness. Fast reactors are open, or, more frequently, enclosed conic tanks with provisions in their lower and narrower part for the intake of raw water and lime. The angle of the reactor funnel cone can range from 15–20°. Figure 10 is a schematic presentation of a fast reactor.

REGENERANT H_2SO_4 INLET
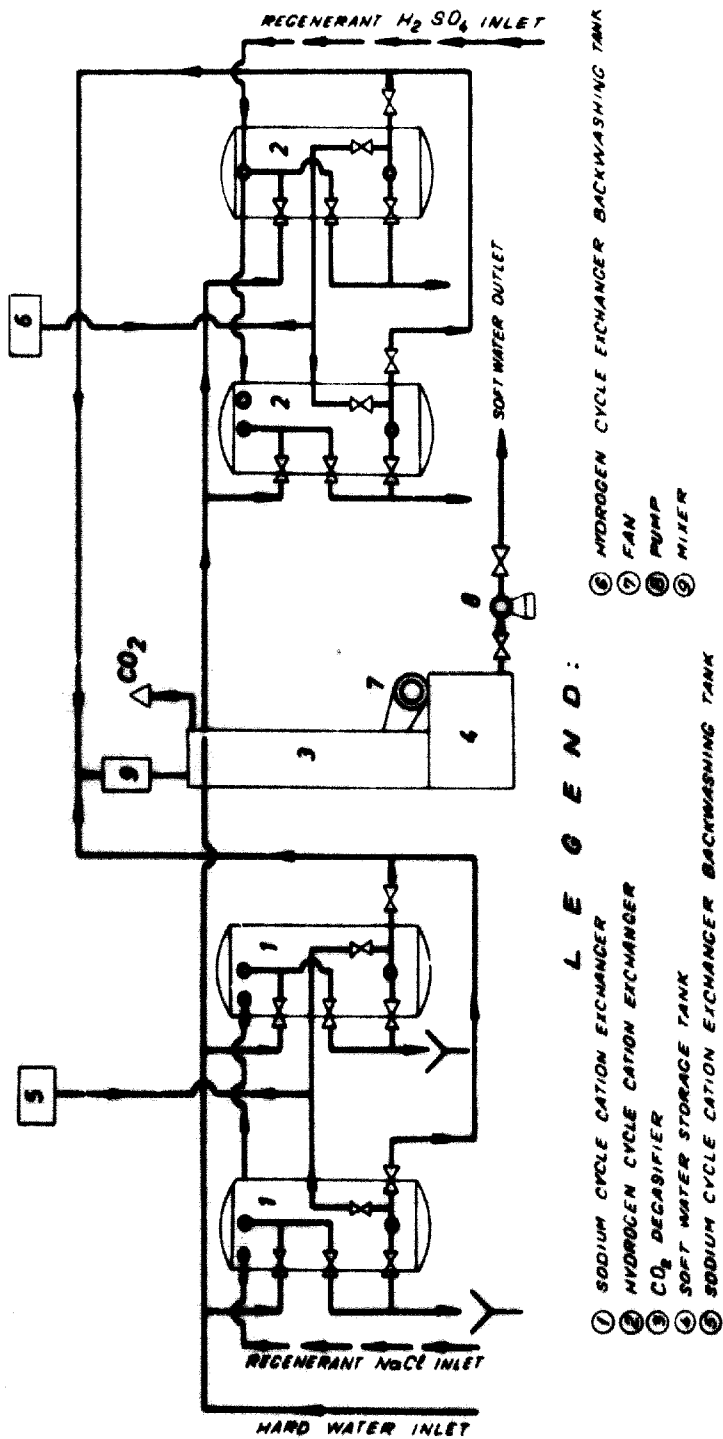
HYDROGEN CYCLE EXCHANGER BACKWASHING TANK

SOFT WATER OUTLET

CO_2

REGENERANT NaCl INLET

HARD WATER INLET

L E G E N D :

① SODIUM CYCLE CATION EXCHANGER
② HYDROGEN CYCLE CATION EXCHANGER
③ CO_2 DEGASIFIER
④ SOFT WATER STORAGE TANK
⑤ SODIUM CYCLE CATION EXCHANGER BACKWASHING TANK
⑥ HYDROGEN CYCLE EXCHANGER BACKWASHING TANK
⑦ FAN
⑧ PUMP
⑨ MIXER

Figure 9. A water-softening plant using parallel sodium-hydrogen cycle cation exchange

LIME TREATMENT

Impurity	Reagent	Precipitate
(1) Removal of calcium bicarbonate		
$Ca(HCO_3)_2$ Calcium bicarbonate	+ $Ca(OH)_2$ Hydrated lime	= $2CaCO_3 + 2H_2O$ Calcium carbonate
(2) Removal of magnesium bicarbonate[a]		
$Mg(HCO_3)_2$ Magnesium bicarbonate	+ $2Ca(OH)_2$ Hydrated lime	= $Mg(OH)_2 + 2CaCO_3 + 2H_2O$ Magnesium hydroxide Calcium carbonate
(3) Removal of free carbon dioxide from the raw water		
CO_2 Dissolved carbonic acid gas	+ $Ca(OH)_2$ Hydrated lime	= $CaCO_3 + H_2O$ Calcium carbonate
(4) Removal of permanent hardness caused by magnesium salts[b]		
$MgSO_4$ $MgCl_2$ $Mg(NO_3)_2$ Magnesium sulphate Magnesium chloride Magnesium nitrate	+ $Ca(OH)_2$ Hydrated lime	= $CaSO_4$ $CaCl_2 + Mg(OH)_2$ $Ca(NO_3)_2$ Magnesium hydroxide

[a] The removal of magnesium bicarbonate requires twice as much lime as the removal of calcium bicarbonate.
[b] The calcium salts formed by this process are removed by reaction with soda ash.

SODA ASH TREATMENT

Impurity	Reagent	By-product	Precipitate
Removal of permanent hardness caused by calcium salts			
$CaSO_4$		Na_2SO_4	
$CaCl_2$ $+$ Na_2CO_3 $=$		$2NaCl$ $+$	$CaCO_3$
$Ca(NO_3)_2$		$2NaNO_3$	
Calcium sulphate	Soda ash	Sodium sulphate	Calcium carbonate
Calcium chloride		Sodium chloride	
Calcium nitrate		Sodium nitrate	

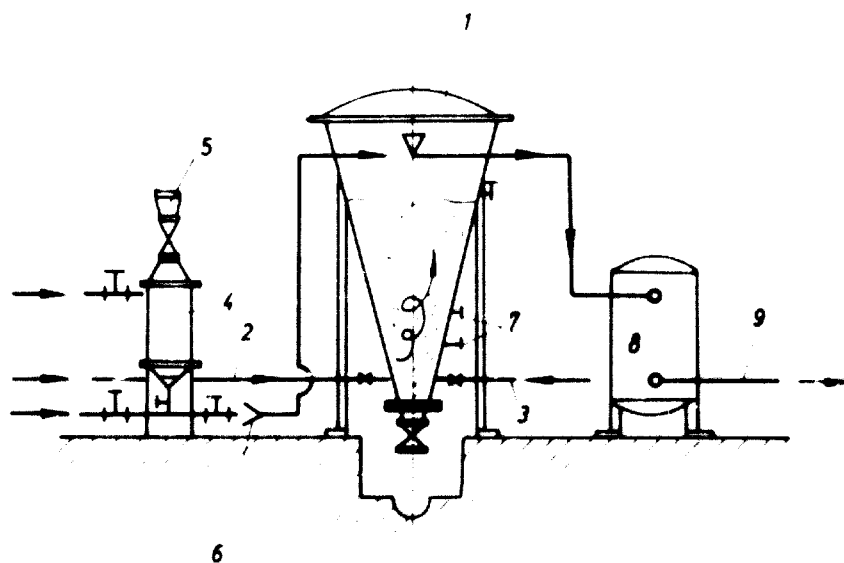*Note:* The by-products of this reaction are the soluble non-scaleforming sodium salts.

74.09.27
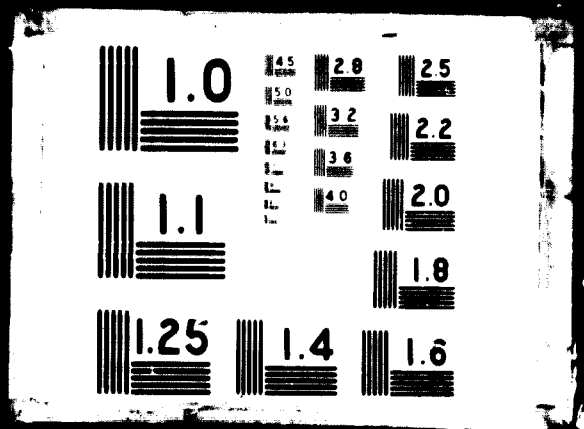
LEGEND:

1 FAST REACTOR   6 EJECTOR
2 RAW WATER   7 SAND OUTLET
3 REAGENT FEED   8 FILTER
4 SAND DOSAGE UNIT   9 SOFTENED WATER
5 FUNNEL FOR SAND FILLING

Figure 10. A reagent water-softening plant with fast reactor

Lime is added continuously in proportion to the raw water flow and to the bicarbonate hardness. It is in the form of milk of lime with $5-6°$ Bé density or of saturated lime water.

The calcium carbonate and magnesium hydroxide precipitates are caught by the sand particles which, when they reach a certain size, drop to the reactor bottom and are periodically discharged. The size of the sand granules when entering the fast reactor is $0.3-0.4$ mm, when discharged, $1.5-2.0$ mm.

The water-softening process in fast reactors takes $5 - 10$ min. The intake rate of the water in the lower section is $0.8-1.0$ m/sec, while the rate at which the water level rises to the decarbonized water discharge outlets is approximately $4 - 6$ mm/sec.

To decarbonize successfully, the plant must have lime-slaking vessels, mixers for the preparation of the milk of lime, milk-of-lime dosage pumps, and instruments for measuring the flow rate, pressure and solution concentration.

Choosing the water-treatment method

The choice of the right water-treatment method is the most important consideration in designing a water-preparation unit. The choice is based on the composition of the raw water impurities and on the water quality required.

Physical and chemical analyses of untreated surface water must necessarily be performed throughout the year, and if necessary through a sequence of years. Depending on the water turbidity and colouration, one-step or two-step clarification and decolourization is applied. In the two-step water treatment the basic mass of the suspended matter is contained in the sedimentation tanks, while the filters serve to complete the process. The maximum capacity of the individual sections of a plant must always be considered; for example, sedimentation tanks with a sludge layer

operate within the range of 100-2,500 mg/l of raw water turbidity. In periods of great turbidity provision must be made for water purification and clarification in large horizontal settling tanks operating without coagulation, where the coarse turbidities settle. Here enormous savings in reagents can be achieved. Sand filters can be applied only with raw water turbidity less than 50 mg/l.

If the water is of high carbonate hardness the combined treatment method is used: water decarbonization followed by water softening by the Na cation exchanger.

A combined Na - H cation exchange can be effected instead of decarbonization. When only partial water softening is necessary, it is performed by means of Na cation exchange, the softened water being mixed with the unsoftened in the proportion required.

The method for removing iron from raw water depends on the form of the dissolved iron.

WATER POLLUTION IN THE VARIOUS BRANCHES OF THE FOOD-PROCESSING INDUSTRY

In the highly industrialized and densely populated areas of the world, rivers are being turned into collectors of industrial and other impurities, with an adverse effect on the health of men, on the plant and animal life of the waterways and on industry itself. With a constantly growing demand for water and continuing pollution of the sources of supply, the reserves of pure water are progressively decreasing. Thus purification of waste water before it is discharged into rivers is essential.

The concentration of the substances contaminating water depends on the production method, the initial raw materials, and the reagents participating in the technological process. Hence the impurities in waste water vary greatly from one industry to another.

The pollution concentration in industrial waste water can be divided into three main groups:

(a) Clean water, obtained from cooling the warm surfaces of the technological installations, etc., that often contains insignificant quantities of the pollutant. In quality this water comes quite close to the initial feed-water.

(b) Slightly polluted water that comes mainly from end-product rinsing, and contains mainly mechanical, mineral and organic impurities, and bacteria. Most of the water used for transportation and washing in the processing plants of the sugar, starch and alcohol industries falls into this category.

(c) Polluted water, whose degree of pollution depends on numerous factors, such as specific water consumption, product quality, technological process stability, etc. In the same factory the water pollution degree can vary at different times in the same operation. Water in this category is contaminated by mechanical impurities and organic matter that are subject to rapid fermentation. It includes the water from filter presses, rinsing of technological equipment in the sugar and dairy industries, etc.

Waste water in the first two categories is used for recirculation or for diluting highly polluted water. All the forms of waste water mentioned are to be found in most factories.

Waste water quality indicators

The data concerning waste water quality are the starting point to be considered in waste water purification, its reusage and disposal, and the recovery of its useful impurities. No less important are the quantitative data, which include information on the daily waste water amounts and the irregularities of waste water formation.

Waste water quality is usually characterized by the following general indicators:

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(a) Colour.

(b) Odour.

(c) Temperature (degC).

(d) Transparence (determined by transparency of a liquid layer poured into a calibrated tube, expressed in cm).

(e) Suspended matter (mg/l).

(f) Sediment per volume (mg/l)—determined after a two-hour settling period of the waste water in a calibrated cylinder.

(g) Sediment per weight (mg/l)—obtained by drying the sediment and suspended matter at a temperature of $105°C$.

(h) Loss by ignition at $600°C$.

(i) $KMnO_4$ (mg O_2 per litre) expenditure. This denotes the amount of oxygen needed for the oxidation of the easily oxidizable compounds in the residual water. It expresses only a part of the oxygen required for the mineralization of the polluted waste water.

(j) Chemical oxygen demand (COD). This denotes the amount of oxygen (mg/l) needed for a complete oxidation of the polluted waste water. By this oxidation, effected by KIO_3 and concentrated sulphuric acid, the nitrogen from the organic matter is transformed into ammonia that reacts with the sulphuric acid to form ammonium sulphate. The hydrogen of the organic matter is transformed into water, carbon into carbon dioxide, and organic sulphur into sulphuric dioxide.

(k) **Biochemical oxygen demand (BOD).** This denotes the amount of oxygen in mg/l necessary for the oxidation of the organic matter in waste water by aerobic bacteria. This quantity is measured at $20°C$ by diluting the sample with distilled water containing a considerable amount of oxygen and nutritious substances.

(l) **Relative stability.** This characterizes the waste water resistance to putrefaction. It is expressed in percentages and denotes the ratio of the oxygen dissolved in the liquid and the oxygen from nitrate and nitrite to the oxygen supply needed for a total oxidation of the polluted waste water.

(m) Dissolved oxygen (mg/l).

(n) Active reaction of the water (pH).

(o) Acidity or alkalinity. This is expressed in ml, N or N/10 of the acid or base solution used for the neutralization of one litre of the residual water.

(p) Quantity (mg/l) of:
Chlorides (Cl^-)
Phosphates (PO_4)
Sulphates (SO_4)
Nitrates (NO_3)
Nitrites (NO_2)
Calcium (CA^{2+})
Magnesium (Mg^{2+})
Carbonic acid (CO_2)
Bicarbonates (HCO_3)

(q) Number of germs per ml.

(r) The most probable number of *B.coli* per litre (faecalic pollution).

Waste water pollution can be of mineral, organic or bacterial origin. Among mineral pollutants sand, clay particles, mineral salts, and dissolved acids and bases have the greatest effect.

Organic pollution can be of vegetable or animal origin. Pollution of vegetable origin is the type most frequently found in the waste water of food-processing plants (the remains of plants, fruits, vegetables and weeds, paper, vegetable oils). Carbon is the basic chemical element in these pollutants. Pollution of animal origin includes excreta, the animal tissue, organic acids, etc. Nitrogen is the basic constituent element of these compounds.

Bacterial pollution is caused mainly by live micro-organisms, such as yeasts and moulds, small algae and various bacteria.

The degree of dispersion in the waste water can be classified as suspended matter, colloidal solution and real solution.

Suspended substances

Suspended matter, the most frequently occurring constituent of waste water, includes mechanical impurities, undissolved matter, etc. Suspended substances may tend to float or sink.

Suspended matter (turbidity) not only gives water in streams an unpleasant appearance but also prevents the penetration of sunlight and adversely influences aquatic life. Because of this the development of microflora and fauna, particularly in the lower stream layers, is greatly retarded. A certain part of the suspended matter settles in the river beds where the river flows slowly. The deposits formed in this way are mainly organic matter decomposed by the metabolic processes of the living world. In the slowly flowing, turbid sections of a stream with no oxygen supply from the surface, the high content of suspended matter in the waterway will cause the formation of anaerobic conditions with a characteristic unpleasant water appearance, offensive odours and gases, etc.

Colloidal and dissolved matter

Waste water is also contaminated with colloids and dissolved matter. Colloids (particles of 10^{-5} cm 10^{-7} cm in diameter) are usually of organic origin (proteins, fats and carbohydrates). Since they cannot be separated from the water by ordinary settling, a coagulant must be added.

Dissolved matter in waste water includes inorganic salts, acids, bases, some organic matter and gases. It is removed by reagent methods, or ion exchangers if this is more economical.

Organic matter and biochemical oxygen demand

The residual water of various food-processing and other industries contains various types of organic matter. Since it is often hard or impossible to determine the concentration of these substances directly, indirect analysis methods are usually used. This is true in particular for those that determine the oxygen required for the oxidation of the organic substances contained in the water.

The quantity of the organic matter is determined by the biochemical oxygen demand (BOD) or the chemical oxygen demand (COD).

Most of the organic substances serve as food for various micro-organisms. As a result of the metabolic activities of the micro-organisms, the organic substances are

mineralized, carbon turning into carbon dioxide, hydrogen into water, nitrogen into nitrates, sulphur into sulphates and phosphorus into phosphates.

The amount of oxygen that the micro-organisms consume in the total oxidation of carbon and hydrogen into carbon dioxide and water is called total biochemical oxygen demand (BOD). Generally speaking, the amount of BOD is proportional to the amount of carbon and hydrogen in the organic substances.

Characteristics of waste water discharged by various branches of the food-processing industry

Most of the water in the food-processing industries is used for washing purposes (beetroot, potatoes, fruit, technological equipment), for raw material transportation (beets, corn), and for cooling. A good deal of this water is polluted in the process. When dealing with the problem of discharging waste water into the waterways it is essential to adhere to the existing regulations and recommendations for the industrial branch in question. The sugar industry's waste water, for example, can be dangerous to fish if discharged into streams when diluted less than 1 : 25. This kind of water contains large quantities of easily oxidizable substances that consume large amounts of oxygen from water.

Mechanical impurities, mainly sand, earth, leaves and roots, are most often found in the disposal waters derived from rinsing and transporting in the factories producing alcohol, sugar and fish products.

Waste water from the dairy industry

The various production units of the dairy industry discharge waste water with different kinds and quantities of pollutants. Thus the conditions of waste water treatment must be determined in each particular case.

A dairy plant can be composed of units for the preparation, pasteurization and packing of liquid milk, the production of powdered milk, cheese, butter and cream, etc.

Milk pasteurization produces refuse that contains a certain amount of milk along with the water used for bottle and equipment rinsing. The processing of milk into butter or cheese leaves a residue of whey, so the waste water contains casein, lactose, albumins and fats. Lactose is one of the particularly undesirable components occurring in dairy waste water. If the waste water does not contain sufficient amounts of oxygen to enable aerobic destruction, lactose is changed into lactic acid, the waste water becomes highly acidic, and the sedimentation of casein in time begins to rot and produce strong and offensive odours.

The water from rinsing the equipment also contains alkalis and other cleansing chemicals.

The basic content of typical waste water derived from dairy plants is listed in table 20.

Waste water from fruit and vegetable canning

Large quantities of water are used in canning and dehydrating fresh fruits and vegetables. The waste water contains substantial amounts of fruit and vegetable juice. To it is added the water used for the maintenance of hygiene on the plant premises. Hence the waste water is heavily polluted by suspended matter and dissolved organic substances and cannot be readily disposed of without polluting the receiving stream. Such waste water can be classified approximately as follows:

TABLE 20

APPROXIMATE CONTENT OF WASTE WATER DERIVED FROM DAIRY PLANTS

	Kind of processing plant						
	Pasteuri-zation	Bottling	Cheese	Butter	Sour milk	Milk-powder	Ice cream
Waste water volume in m³ per ton of processed milk	1.5	2.10	1.67	0.92	1.25	1.25	—
Waste water properties							
Total solids (mg/l)	1,141	1,483	1,582	2,422	2,793	2,407	—
Suspended matter (mg/l)	—	536	751	664	754	—	—
BOD (mg/l)	509	567	998	1,246	1,291	485	—
Waste water pollutants	Milk, Rinsing water	Milk, Rinsing water	Whey, Casein, Rinsing water	Residue of milk processing, Rinsing water	Spoilt milk, Rinsing water	Spoilt milk, Rinsing water	Casein, Rinsing water

(a) Water derived from pasteurization and cooling of the equipment.

(b) Water derived from rinsing and bleaching of products and cleaning the installation and equipment.

(c) Solid waste.

(d) Waste obtained from specific products or specific canning methods

Waste water from canning plants also carries along sand and mud (from product washing) and refuse (fruit and vegetable peels, pods, vegetable fibres).

Since plants for canning vegetables and fruits operate when the individual kinds of fruit and vegetables are ripening, waste water problems arise only during the corresponding season. Most plants are capable of processing and canning several kinds of vegetables and fruits and thus can operate continuously throughout the season. In this case, they often operate round the clock to prevent spoilage, with the result that enormous quantities of waste water are produced that require speedy purification and disposal.

The volume and characteristics of the waste water of the canning industry vary considerably with the product. Studies of the biochemical oxygen demand (BOD) for the waste water of particular branches have yielded very different results. In asparagus canning the BOD does not exceed 100 mg/l; in fruit juice production it reaches the value of 4,000 mg/l and with very concentrated wastes even 75,000 mg/l. By cont.ast municipal waste water has a BOD of approximately 200 mg/l.

Table 21 lists the necessary quantities of water and some of its properties in the treatment of various kinds of fruits and vegetables.

TABLE 21
THE WATER QUANTITY REQUIRED, BOD VALUES AND THE QUANTITY OF SUSPENDED MATTER FOR VARIOUS PRODUCTS

Product	Volume of waste water (gallons/case)	BOD (mg/l)	Suspended matter (mg/l)
Apricots	57 – 80	200–1,000	260
Asparagus	70	100	30
Beans	26– 44	160– 600	60– 85
Beets	27 – 65	1,600–5,500	750–2,200
Carrots	23	520–3,000	1,850
Cherries (sour)	12– 40	700–2,100	20 – 600
Grapefruit	5– 56	310 2,000	170– 290
Melons	20– 42	2,850–6,900	790–2,500
Mushrooms	6,600	75– 400	50– 250
Peaches	45– 60	1,350	600
Peas	14– 56	380–4,700	272– 400
Sauerkraut	20– 43	6,300	630
Spinach	160	280– 730	90– 580
Tomatoes	38–100	180–3,400	170–1,200
Wheat	25– 70	1,150–6,000	300–4,000

Despite the great pollution that these residual waters spread, a large number of canning factories have not yet started intensive purification of their waste water, and for several reasons. Most of them operate seasonally, so an investment in their own waste water purification plant is too costly. At the same time, the character of the waste water greatly varies even during a single day. Beetroot, for example, produces coloured waste water; sauerkraut waste water has a sharp odour; processing of roots gives the water a high content of suspended matter; wheat processing yields white waste water called wheat milk; lemon processing makes the waste water very acidic, etc. It is difficult to set up a satisfactory plant for treating such diverse waste water.

Waste water from the meat-processing industry

Waste water from the meat-processing industry has a very high concentration of easily putrefied organic substances. The amount of water required is normally calculated according to the number of animals to be processed, but its quantity and degree of pollution may be quite variable.

Table 22 gives average waste water pollution value in slaughter-houses.

TABLE 22
AVERAGE SLAUGHTER-HOUSE WASTE WATER POLLUTION

Livestock	Required quantity of water (m^3/t)	BOD (mg/l)	Suspended matter (kg/t)	Nitrogen (kg/t)	Fats (kg/t)
Beef	12.3	12.5	11.4	1.45	0.98
Hogs	16.3	14.2	9.2	1.43	1.50

This kind of waste water contains raw and intestine secretions, blood, fats and other organic substances. Here too, as with other food-processing plants, the water amounts vary not only daily but also hourly.

Waste water in the sugar industry

The waste water of the sugar industry contains a large quantity of poisonous refuse susceptible to putrefaction. The waste water originating from the washing and transport of sugar beets has a low BOD and a high concentration of suspended substances; that from the diffusion vessels and presses has a very high BOD and contains fine suspended matter. The water originating from the sugar processing itself contributes only 15 per cen' of the total volume of the sugar industry's waste water.

Relative quantities and qualities of this waste water are listed in table 23.

The sugar industry's waste water is best purified by running it through screens, coarse settling chambers, and settling tanks.

Waste water from fermentation processes

Water is used in the fermentation industries (spirits, beer, wine, yeast, etc.) for washing and classifying raw materials, for cooling, and for technological purposes such as rinsing bottles and equipment. The waste water contains particularly harmful fermentation products that must never be discharged into waterways.

Table 24 gives the composition of fermentation residue and waste water from the spirits industry.

TABLE 23

RELATIVE AMOUNTS AND COMPOSITION OF THE SUGAR INDUSTRY'S WASTE WATER

Characteristics	Sugar beet transportation water		Lime precipitate	Process waste water
	Case A	Case B		
Water volume (m³/t) of beets)	7.5	7.5–11	0.3	1.2
Suspended matter (mg/l)	800	400	450	1,300
Volatile matter (%)	–	35	–	75
Total substance (mg/l)	1,200	1,200	3,310	–
BOD (mg/l)	200	200	1,420	1,600
COD (mg/l)	110	175	500	1,500

TABLE 24

FERMENTATION RESIDUE AND WASTE WATER CONCENTRATION DERIVED FROM THE SPIRITS INDUSTRY

		Water	
	Fermentation residue	Washing and transport of raw materials	Washing of barrels
Dry residue (mg/l)	25,510	540	2,450
Ignition residue (mg/l)	6,218	320	956
Oxidizability (O₂ mg/l)	28,258	45	280
Biochemical oxygen demand (BOD)	41,340	–	1,210
pH	6.4	7.05	7.21
Alkalinity (meq/l)	4.8	4.5	10.6

Per 100 kg of potatoes entering the process in a spirits plant 10 kg of wet sediment with a specific gravity of approximately 1,800 kg/m³ is obtained. However, according to sanitary regulations no litre of waste water discharged into the stream may contain more than 30 mg of mineral and 10 mg of organic substance.

The content of waste water derived from beer- and malt-producing plants is presented in table 25.

TABLE 25

WASTE WATER CHARACTERISTICS IN BEER- AND MALT-PRODUCING PLANTS

Quality indicator	Unit	Beer plant	Malt plant
Turbidity	cm	6.5	16
Colour		Yellow-greyish	Light yellow
pH		5.6	6.52
Oxidizability	mg/l	608	625
Free oxygen	mg/l		
BOD	mg/l	1,800	1,600
Dry residue	mg/l	481	1,526
Ignition residue	mg/l	237	414
Loss by ignition	mg/l	244	1,112
Suspended matter dried at 105°C	mg/l	88	62

Waste water of wine-fermenting plants contains the residual water from the grape presses, the wine-cell sludge and the refuse water resulting from the hygienic maintenance of the plant. This waste water is highly coloured and therefore is not permitted to enter streams.

The waste water of yeast-producing plants presents great problems because of the high content of proteins, which rapidly decompose and release unsavoury gases.

Table 26 lists the content of the waste water of yeast-producing plants.

TABLE 26

WASTE WATER CHARACTERISTICS OF YEAST-PRODUCING PLANTS

Quality indicator	Unit	After the first yeast extraction	After the second yeast extraction	At the end of the process
Colour		Dark yellow	Dark yellow	Dark yellow
pH		6.0	6.5	4.1
Total nitrogen (N_2)	mg/l	271	56	42
Oxidizability	mg/l	2,430	40	450
BOD	mg/l	8,300	1,100	1,100
Dry residue	mg/l	9,178	1,746	1,696
Ignition residue	mg/l	3,086	578	1,012
Loss by ignition	mg/l	6,092	1,168	684
Sulphates (SO_4^-)	mg/l	938	113	--

WASTE WATER PURIFICATION IN THE FOOD-PROCESSING INDUSTRY

The science of waste water purification is a relatively new one, for the problem of waste water purification has aroused interest only very recently. Nevertheless, a set of principles has been formed that must be adhered to unconditionally.

When the composition of indust.ial waste water is such that chemical interaction releases various poisonous gases or results in large quantities of insoluble matter settling in the collector, this water should not be discharged into the sewage collectors. The disposal of the concentrated basic solutions should be decided in each case separately, since their direct disposal into the sewage system is not permissible.

When industrial waste water is very acid the sewage ducts should be covered with acid-resistant materials such as cement or plastics. Asphalt and bitumen protective materials are often not resistant to organic solutions (gasolene, benzol) and high temperatures.

Certain industrial plants routinely or at times of breakdown discharge waste water in batches. They must have storage tanks with a volume adequate to regulate the discharge of the water into the sewage system and the purification plant. Equalization tanks, in which the necessary uniformity of the waste water composition is achieved by mechanical mixing and reciprocal chemical action, are also essential.

If different factories are in the same locality it is very desirable to provide for a joint treatment of the waste water. Sometimes the waste water of one plant can be used very effectively as a reagent for the treatment of the waste water of another plant, in which case a common sewage system has obvious advantages.

Waterways—waste water recipients

The most simple and economical way to dispose of waste water is to discharge it into the nearest stream.

When untreated or insufficiently purified waste water of industrial plants and municipal communities is discharged into streams, the following water quality changes take place in the receiving waterways:

(a) The physical features of the water change (turbidity, colour, odour).

(b) Floating substances appear on the surface and sludge on the bottom.

(c) The chemical properties of the stream change (pH, organic and inorganic impurities content, formation of poisonous substances).

(d) The amount of oxygen dissolved in the water decreases.

(e) The number and kind of bacteria change.

(f) Aquatic life is destroyed.

The physical processes of this type of disposal include dilution of the waste water by the stream water. and this can lead to a substantial decrease in the concentration of the pollutants. The chemical process that occurs is the neutralization of acids or bases with the bicarbonates and carbon dioxide from the water of the recipient waterway. The biochemical processes are reflected in the mineralization of the organic pollutants by the metabolic processes of the living organisms in the waterway.

Through these processes the concentration of the pollutants is reduced, in some cases to zero. Thus streams are said to have an autopurification ability and can be considered natural purification plants. Yet the autopurifying power of the waterway is limited. It depends mainly on the volume of the water in the stream, on the quantity and composition of the waste water being discharged into it, and on the time available for the purification process. The purification ability of the waterway has great sanitary and economic significance.

The amount of waste water of a particular composition that the waterway can receive without incurring any harmful effects must be established in each case by computation starting from the purification power of the stream. When the stream purification ability is insufficient, waste water must be purified or it cannot all be disposed of into the stream.

About 60 per cent of waste water pollution is made up of dead organic matter, the greater part of which is dissolved (c. 55 per cent) but some of which floats on the water surface (c. 18 per cent). This matter is continuously being mineralized as a result of the activity of aerobic micro-organisms if the oxygen supply is greater than the oxygen consumption in the oxidation process. If not, the amount of dissolved oxygen in the water will drop and can be completely exhausted, in which case anaerobic conditions occur.

Temperature has a great influence upon the oxygen situation and the autopurification ability of the waterway. When the temperature rises the rate of oxidation of the organic matter goes up, while the oxygen solubility drops. In summer months the pollutant concentration is greatest.

At high temperatures the waterway's oxygen balance is easily disrupted, particularly with insufficient aeration. In winter months the oxygen solubility in the stream rises, while the intensity of the biochemical processes of the micro-organisms weakens. This slows down decomposition of the organic matter, and consequently waterway autopurification.

The pH of stream water tends to be maintained near neutrality if it contains reasonable quantities of the bicarbonates $Ca(HCO_3)_2$ and $Mg(HCO_3)_2$, since these substances can neutralize corresponding quantities of acids or bases.

Conditions for the disposal of waste water into waterways

Waste water discharged into waterways must be of such a degree of purity that it will not harm aquatic life and can be used for industrial purposes and even for drinking under certain circumstances. The maximum concentration allowed is determined by every country depending on its specific conditions.

Waterways can be divided into those intended for (a) sanitary purposes and human consumption and (b) for pisciculture. The composition and properties of stream water must be the standards listed in table 27 at a check post located at least 1 km upstream from the intake to the water-pumping station.

TABLE 27

MAXIMUM CONCENTRATION OF HARMFUL SUBSTANCES
IN STREAM WATER

Element or compound	Concentration (mg/l)	
	Water for sanitary and human usage	Water for pisciculture
Lead	0.1	0.1
Arsenic	0.05	0.05
Fluorine	1.5	No regulation
Cyanides	0.1	0.05
Copper	0.1	0.01
Zinc	5.0	0.01
Nickel	0.1	0.01
Cobalt	1.0	No regulation
Chlorine (free)	None	None
Hydrogen sulphide	1.0	1.0
Turpentine	0.2	No regulation
Styrene	0.1	No regulation
Chromium	0.1	No regulation
Iron	0.1	No regulation
Manganese	No regulation	No regulation
Ammonium	No regulation	50.0
Ammonium salts	No regulation	0.1
Tannin	No regulation	10.0

The initial increase in concentration of the suspended matter must not be greater than 0.25 mg/l for waterways of the first category and not greater than 0.75 mg/l for those of the second. Irrespective of the season, the concentration of dissolved oxygen must not be less than 4 mg/l in any waterway and not less than 6 mg/l in waterways used for pisciculture.

Waste water purification: methods and equipment

For the partial or complete elimination of toxic substances in waste water a variety of methods and equipment exists. Table 28 illustrates the effects of the simplest methods of waste water purification expressed as the percentage decrease in BOD, the suspended matter and bacteria.

TABLE 28

EFFICIENCY OF PURIFICATION METHODS EXPRESSED AS PERCENTAGES
OF THE SUBSTANCES ELIMINATED FROM WASTE WATER

Purification method	BOD	Suspended matter	Bacteria
Fine screens	2–20	15–20	10–20
Settled waste water chlorination	15–30	–	90–95
Normal sedimentation (2h)	25–40	40–70	25–75
Chemical precipitation (coagulation and sedimentation)	50–85	70–90	40–80
Normal sedimentation with quick filtration	50–90	80–95	–
Normal settling, biofilter and secondary sedimentation	80–95	70–92	90–95
Normal settling, active carbon and secondary sedimentation	85–95	85–95	90–98
Biological treatment and chlorination	–	–	98–99

This table enables the selection of the most suitable method of waste water purification in the simplest cases. The exact content of the waste water is determined by chemical analyses and approximate standard tables of the average composition of municipal and industrial waste water, taking into consideration the given dilution (water consumption).

Elementary methods that can be used for waste water purification include mechanical, chemical, physicochemical, and biological.

By mechanical purification the pollutants generally found in insoluble or partly colloidal form are eliminated. Coarser particles and industrial waste (rugs, paper) are held back by a screen. Fine waste found in water in a suspended form is removed by a sieve or sand traps. Most of the pollutants are of mineral origin whose specific gravity is considerably greater than that of water (sand, dross, etc.) and are therefore separated in sand traps. Suspended pollutants of organic origin are removed from the liquid mainly in settling tanks. Substances lighter than water (fats, grease, naphtha, tar) float to the surface and are removed. For the separation of these substances from industrial waste water very often fat and oil traps are used.

By using chemical and physical methods (neutralization, floatation, adsorption, extraction, etc.) mainly insoluble and soluble matter is removed as partly colloidal waste water pollutants.

Biological purification results from the metabolic activity of micro-organisms that break down the organic matter into a colloidally dispersed state. Almost total

removal of the organic matter left after mechanical purification can be effected by this method. A biological purification plant can operate under (a) conditions close to those prevailing in nature (irrigation fields, lakes) or (b) conditions that are artificially created (biofilters, aerofilters, aerotanks).

Mechanical and biological purification produces large quantities of sludge, and this sludge tends to putrefy. Special equipment for treating the sludge (septic pits, methane tanks, sludge-drying beds, etc.) is therefore necessary.

Equipment for mechanical purification of waste water

The equipment for mechanical purification includes screens, grinders, sand settlers, fat and oil traps, settling tanks and the waste water mixing and equalization tank.

Large quantities of fat and oil waste are found in the effluent of edible and technical oil-processing plants such as slaughter-houses and meat-processing plants. They are removed from the waste water by special equipment called fat traps. Such equipment is necessary to avoid tube choking, to ease the load on biological equipment for treating the remaining organic pollutants and to permit reuse of the recovered oils and fats.

A fat trap (figure 11) is made in the form of a rectangular tank with an average depth of 2 m. The waste water is usually detained in these tanks 5-7 min. A special submerged partition is located some 30-40 cm from the equipment bed. In special types of traps air is introduced to improve the separation of these materials.

Settling tanks are used to separate suspended matter and colloids. They are used when sanitary regulations require only the removal of mechanical impurities. They may also be used for preliminary purification if the waste water is to be sent afterwards for biological treatment. With respect to location, settling tanks are divided into two categories: those located before the biological purification equipment (primary); and those located after (secondary).

Settling tanks can be horizontal, radial or vertical. Horizontal settling tanks, where the removal is done horizontally, are used when relatively large quantities of waste water have to be treated (up to 20,000 m³/day). Radial settling tanks operate on the same principle as the horizontal ones, but the horizontal water flow is directed from the centre towards the periphery. They are also used to process large quantities of waste water (over 20,000 m³/day). Vertical settling tanks are designed so that the water flows by backwashing (from the bottom upwards). They are used for treating relatively small quantities of waste water (less than 10,000 m³/day).

When deciding on the type of settling tank one must consider several factors: waste water quantity; sludge quantity and its features (condensing ability, putrefaction tendency); sludge removal from the tank and subsequent sludge treatment; local conditions, such as land relief, underground water level, construction materials; and a whole series of techno-economic parameters.

Equipment that can clarify industrial waste water of all kinds, particularly if the waste water is first coagulated, is installed adjacent to the settling tanks. In contrast to the settling tanks, which are relatively insensitive to changes in the waste water feed and temperature, the clarification equipment may be damaged when relatively small changes in temperature of the influent occur.

The basic data for making the hydraulic and technological calculations for settling tanks of all kinds include the quality of the waste water, the water and sludge density, and the sedimentation kinetics of the insoluble impurities.
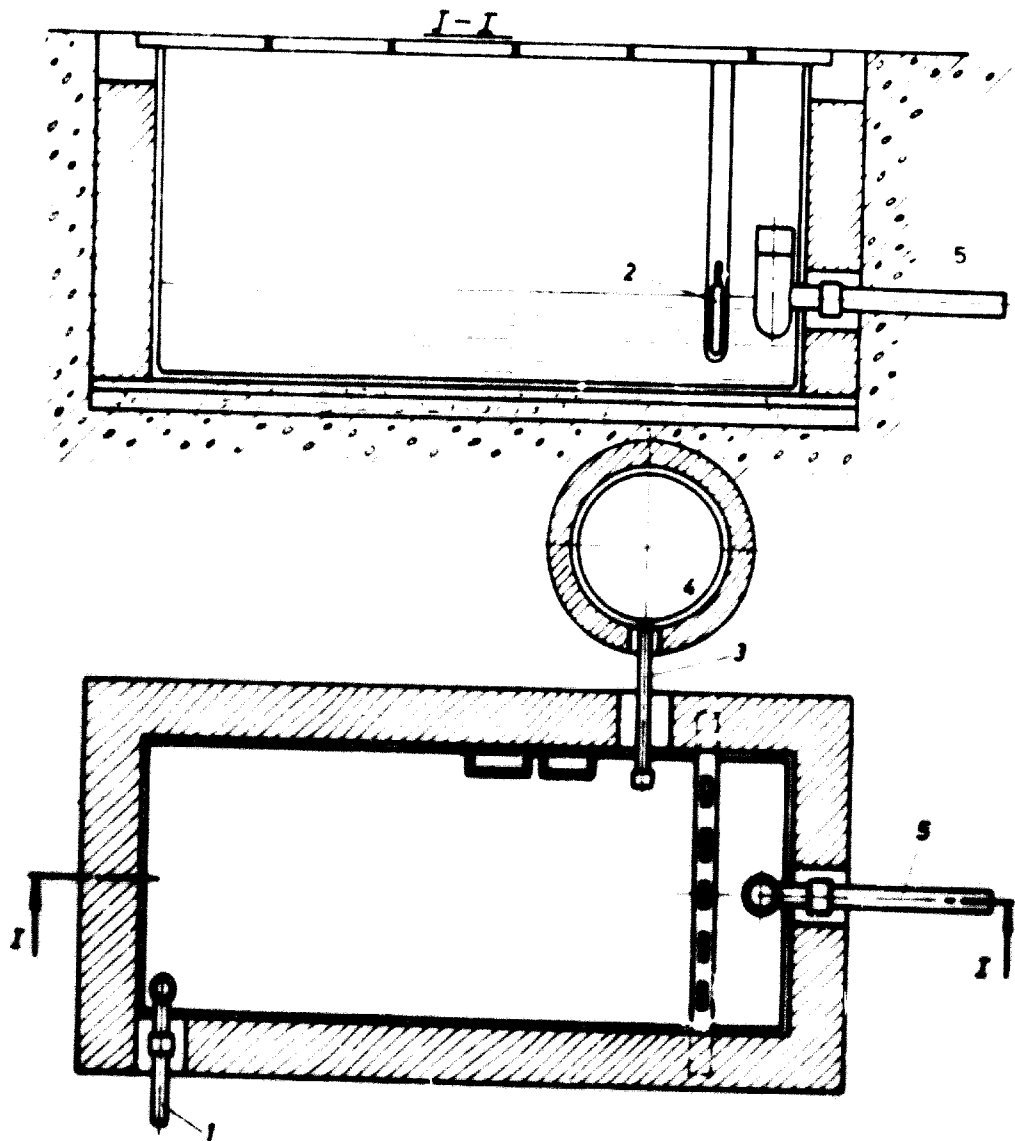
LEGEND:
① WASTE WATER FEED
② SUBMERGED PARTITION
③ FAT OUTLET TUBE
④ FAT RESERVOIR
⑤ WATER REMOVAL PIPE

Figure 11. Plan of a fat trap

The composition and quantity of industrial waste water are generally quite variable because of uneven usage of the water in the production process. This variability greatly complicates the designing of an industrial sewage system, and particularly the operation of purification plants. Great variations in the waste water feed disrupt the normal functioning of the settling tanks and filters, and changes in the waste water content hamper the normal operation of the neutralizing and oxidizing equipment. Therefore it is necessary in most cases to balance the waste water content. This is effected either by mixing waste waters of different content or

by introducing various reagents into the waste water. In the first case equalization equipment is used, and in the second a mixing apparatus.

Natural or small artificial lakes and special equalization tanks are used to equalize the waste water concentration. Despite their relatively large volume the equalization effect obtained is usually not high because it depends on the water flow, temperature oscillation, wind etc.

Mixing equipment most frequently comprises narrow basins with perforated partitions or mechanical mixers. The latter are notably more efficient because of a far smaller pressure drop in the main waste water flow. They are also efficient under conditions of uneven feed. In some ways they are advantageous when a reagent is to be introduced later into the waste water.

Chemical methods of waste water purification

The most important chemical methods of waste water purification are coagulation, neutralization, and chlorination (which can also be considered a biological purification method).

In the coagulation process the suspended and colloidal substances that are not separated by normal sedimentation settle. For this purpose certain reagents (aluminium sulphate, ferrous sulphate, ferric-chloride and sometimes even their mixtures) are added to the waste water prior to its introduction into the settling tank.

Neutralization is indispensable in the treatment of waste water containing a large amount of acids and bases if their disposal into the sewage system or the waterway is not permitted. Some of the neutralization methods used include:

(a) Direct mixing of acidic and basic waste waters prior to their discharge into the sewage system.

(b) Mixing of acidic waste water with basic sewage water.

(c) Addition of a neutralizing reagent (lime).

Acidic waste water is more frequent than alkaline. Highly acid waste water affects the life in the waterway and the purification equipment unfavourably. Industrial waste water contains: strong acids (hydrochloric and nitric) whose calcium salts easily dissolve in water; strong acids (sulphuric) whose calcium salts poorly dissolve in water; and weak acids (acetic acid).

Neutralization of strong acids whose calcium salts have low solubility is extremely complex because of the resulting large amount of sludge. This sludge, besides requiring a settling plant, slows down the process of neutralization because it is gathered on the surface of the substance to be neutralized. Neutralization of acids whose calcium salts dissolve easily is relatively simple.

Physicochemical methods of waste water purification

Physicochemical methods of waste water purification include extraction, adsorption, and flotation.

Extraction is based on the difference in solubility of the pollutant in two immiscible liquids that are brought into intimate contact. The organic solvents that do not mix with water (benzene, mineral oil, carbon tetrachloride, etc.) are usually used as the extraction agents. The extraction is effected in columnar metal tanks. A solvent whose specific gravity is less than that of water is added from below and rises to the top. The waste water is introduced from above and drops to the bottom,

where it is discharged. The water on its way down comes into contact with the solvent and is gradually freed of the pollutant. Today extraction is used mostly for the removal of phenol, notably in the Federal Republic of Germany.

Many industrial wastes contain organic substances in low concentration that are difficult or impossible to remove by conventional biological treatment. Examples are detergents and some of the heterocyclic organics. These materials can frequently be removed by adsorption on an active-solid surface. The most commonly used adsorbents are activated carbon and silica gel. There are two principal ways of adsorption treatment: mixing of the waste water with a certain amount of the adsorbent, with additional sedimentation (static adsorption); and filtration of the waste water through the layer of an adsorbent (dynamic adsorption).

Floatation is used to remove solids from waste water. The waste water is saturated with air under pressure. When this pressurized air-liquid mixture is transferred into the floatation unit under atmospheric pressure, minute air bubbles are released from the solution. These air bubbles become enmeshed in the floc particles and bring them to the surface, where they are skimmed off. The clarified liquid is removed from the bottom of the floatation unit, and a portion of the effluent may be recycled to the pressure chamber.

Biological methods of waste water purification

Water can be biologically purified anaerobically or aerobically. Anaerobic decomposition (occurring in the absence of oxygen) involves the breakdown of organic wastes by facultative and anaerobic organisms to organic acids, and the subsequent breakdown of these acids to methane and carbon dioxide. The methane organisms are strict anaerobics. Aerobic decomposition (occurring in the presence of oxygen) is brought about by a whole series of micro- and macro-organisms, while in the anaerobic autopurification process practically only bacteria participate.

The waste water of many industrial plants contains large amounts of organic substances, the concentrations of which can exceed even by tenfold the concentrations in domestic waste water. Full removal of these organic substances is possible only by biological purification. The biochemical processes in industrial waste water purification are the same as in domestic waste water purification. However, the rates are usually lower, especially if the industrial waste water contains substances toxic to the biological process.

The basic factors influencing biological purification are:

(a) Susceptibility of the organic matter to decomposition by the micro-organisms.

(b) Pollutant concentration.

(c) Presence of concentrated substances that could have a toxic effect upon the micro-organisms.

(d) Presence of the necessary nutritive matter (nitrogen, phosphorus, potassium).

(e) Active reaction (pH) of the waste water.

Micro-organisms biochemically decompose most organic compounds, with some exceptions, such as certain organic chlorine compounds. The biological activity of the micro-organisms depends on the concentration of the organic matter in the waste water. For each compound there is an optimum concentration, above which the biological activity of the micro-organisms weakens and ultimately ceases.

Numerous industrial waste waters contain compounds that are toxic to micro-organisms. For instance, at a copper concentration of 0.1 mg/l the biochemical process is not obstructed, at a concentration of 0.5 mg/l the decomposing processes are considerably slowed, and at 10 mg/l they stop. Cyanides affect the oxidation of ammonia into nitrates at a concentration as low as 0.5 mg/l.

The two most important processes in biological purification of waste water — and they may sometimes be combined to advantage — are treatment on percolating filters and by activated sludge. Both require oxygen.

In percolating filters air flows up freely through the filter medium from the base as a result of the natural internal and external temperature difference. This difference is increased by the bacterial activity itself. The liquor to be treated is spread evenly over the surface of the filter medium by rotating distributors. In its downward passage over the medium a biological film is formed in which the organisms essential to the process thrive. This film also promotes the growth of worms, larvae and other life which feed upon it and thus keep it from choking up the interstices of the medium. Because of this activity part of the film usually breaks away and is discharged with the effluent as humus or fine suspended matter.

The activated sludge process depends upon mechanical aeration of the effluent in a suitable tank. In one form compressed air is blown into the liquid through porous diffusers; in other forms the surface of the liquid is violently agitated by electric power so that it absorbs atmospheric oxygen. When an organic effluent is aerated, a biologically active sludge is formed. The sludge flowing away with the effluent is collected and reintroduced into the aerating tank. This mixture of active sludge and effluent in the presence of oxygen oxidizes the organic matter. Some effluents do not build up an active sludge readily and may require seeding with suitable bacteria. Domestic sewage greatly assists in sludge formation, but a sufficient quantity is often not available.

The humus sludge from percolating filters must be separated out before the effluent can be discharged into a river. This is carried out in settling tanks similar to those used for primary settling. Then the humus sludge is usually returned into the primary sedimentation tanks, where it settles along with the much coarser primary sludge.

In activated sludge plants the settling tanks must be of a type that permits continuous desludging. The sludge rapidly decomposes and must be removed promptly from the settling tank. This removal is effected by mechanical sludge scrapers, which must be specially designed to ensure complete coverage of the floor. The excess of activated sludge built up during the process must be disposed of; usually it is sent back into the primary tank.

Whatever means of disposal is adopted, the first requirement is to reduce the bulk of the material by removing as much water as possible. The simplest means is to run the wet sludge on to drying beds, which are shallow beds of ash, under which the liquor from the sludge is drained away. The sludge then dries off and can be carted away. Very often this method requires considerable space, and it may be more economical to remove water from the sludge mechanically in pressure or continuous-vacuum filters.

These methods can also be used in conjunction with anaerobic digestion. In this process the sludge is allowed to stand in a suitable tank for a number of days, where under proper conditions it will ferment. This considerably reduces the bulk of sludge, which loses its offensive nature and becomes much easier to handle.

The digestion process liberates gas with a large proportion of methane. If the scale of the plant warrants the capital expenditure, this gas can be collected and used for power.

Figures 12 and 13 are diagrams of the processes of biological purification of waste water discussed above.
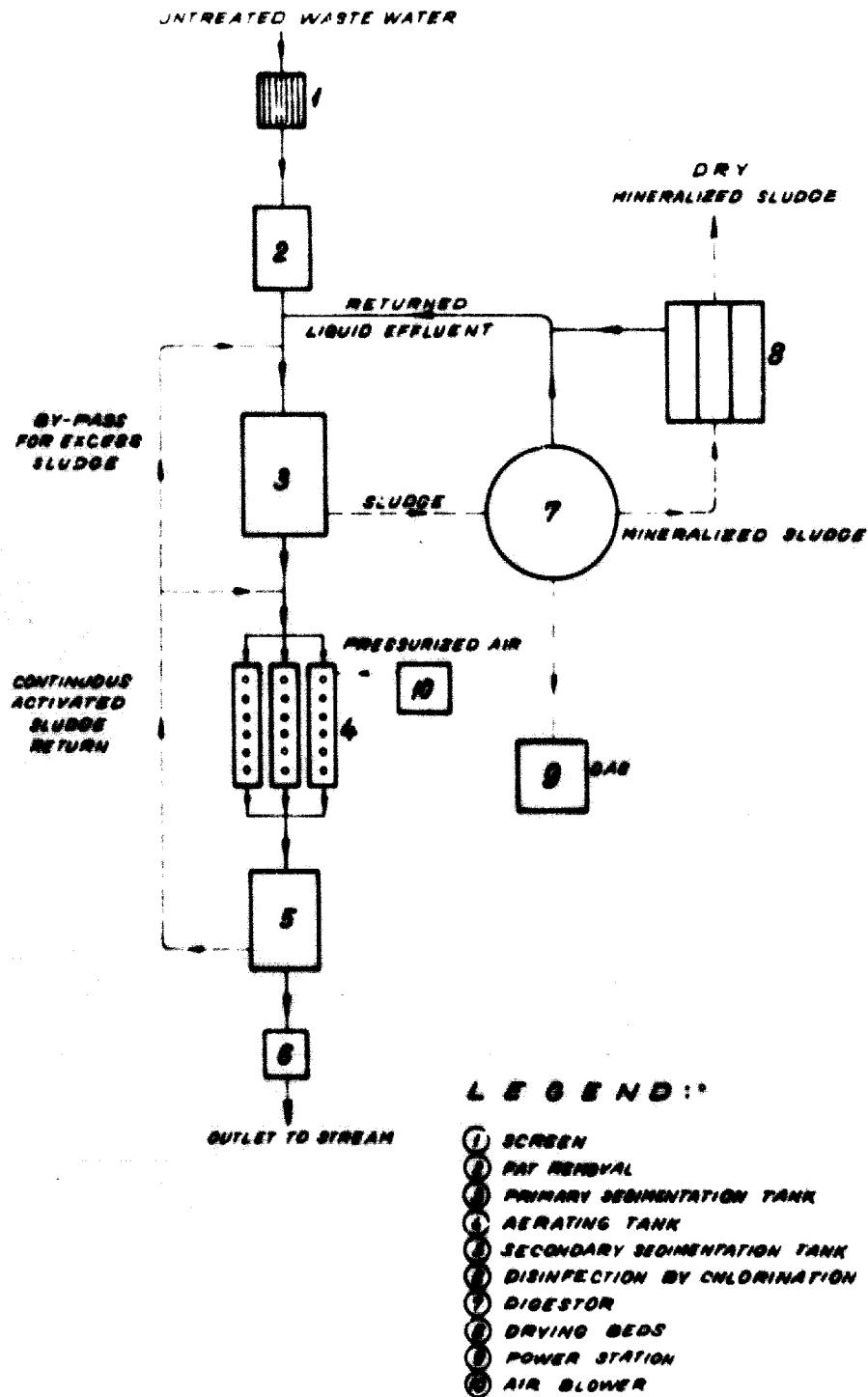

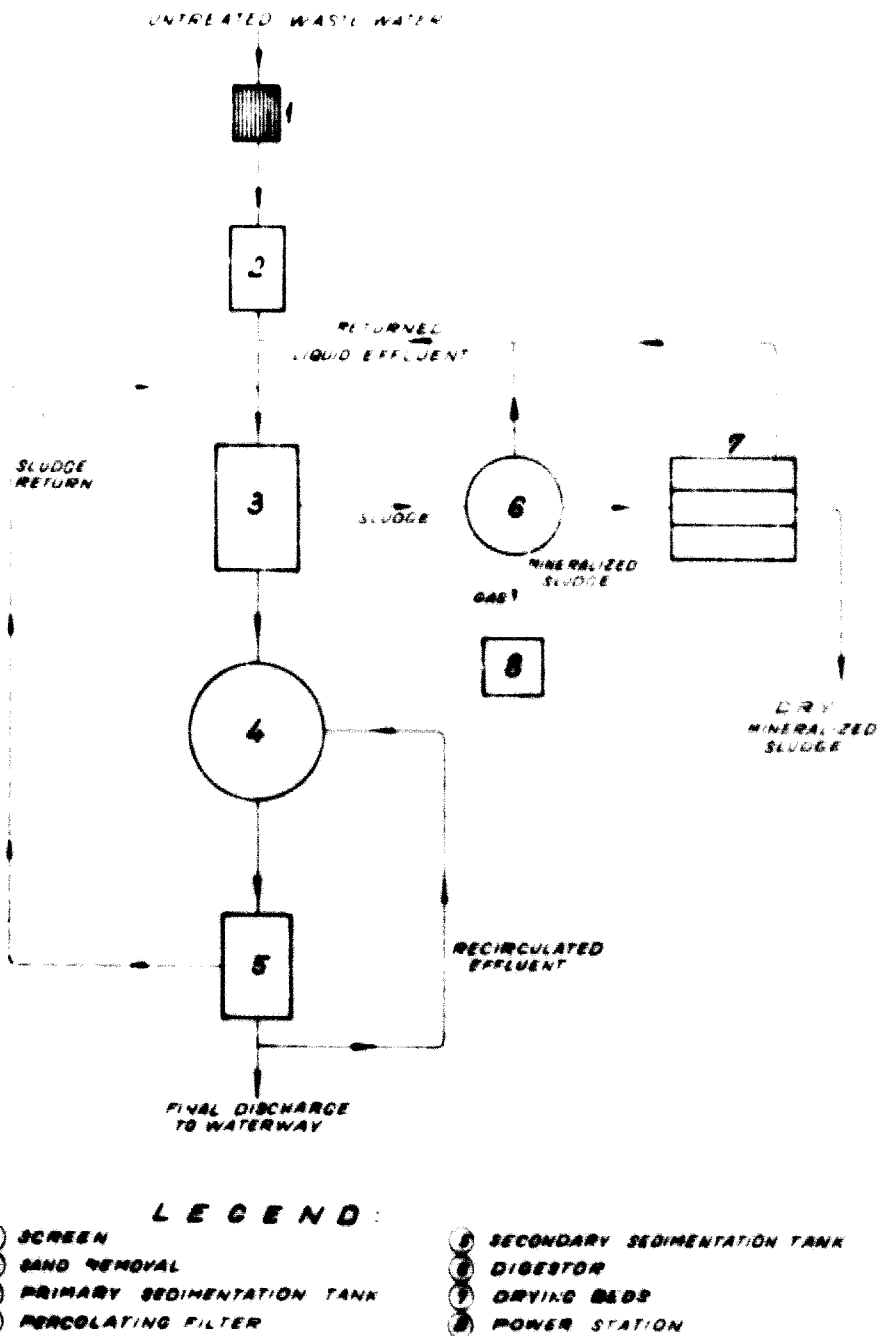*Figure 12. An activated sludge plant for treatment of waste water from the meat industry*

UNTREATED WASTE WATER

RETURNED
LIQUID EFFLUENT

SLUDGE
RETURN

SLUDGE

GAS

MINERALIZED
SLUDGE

DRY
MINERALIZED
SLUDGE

RECIRCULATED
EFFLUENT

FINAL DISCHARGE
TO WATERWAY

LEGEND:

① SCREEN
② SAND REMOVAL
③ PRIMARY SEDIMENTATION TANK
④ PERCOLATING FILTER

⑤ SECONDARY SEDIMENTATION TANK
⑥ DIGESTOR
⑦ DRYING BEDS
⑧ POWER STATION

Figure 13.   Flow chart of a percolating filter plant for purification of waste water from the sugar industry

Waste water disinfection—chlorination

Although approximately 95 per cent of the bacteria in waste water is destroyed by biological purification, their total destruction can be achieved only by disinfection. Disinfection is effected most commonly by chlorination, but also sometimes by electrolysis, ultra-violet light, etc.

Chlorine doses, expressed in grams of chlorine per m^3 of waste water, depend on local conditions, the waste water purification method, and the waterway. They can be classified as follows: for waste water mechanically purified, 25 g/m^3; for the

waste water not fully purified in the aeration tanks and percolating filters, 10–15 g/m^3, and for waste water fully purified in the aeration tanks and percolating filters, 5–10 g/m^3.

A chlorinating plant using chlorinated lime consists of a unit for preparation of the chlorinated lime solution, accessories, mixer and a contact reservoir. The solution, whose concentration is 10–15 per cent, is transferred to the dosage tank, where it is diluted to 2–3 per cent. It is then fed into the sedimentation reactor, where besides acting as a disinfectant it promotes coagulation and complementary sedimentation.

ECONOMIZING WITH WATER IN INDUSTRY

A good illustration of industrial water conservation is the closed (recycled) cooling system discussed earlier (p.20). This system is becoming the only economic one for industrial regions with limited sources of water. The costs of construction, operation, and maintenance of this type of system compare favourably with the costs of discovering new sources of raw water.

Stepwise water utilization

When water is scarce or when water processing is very expensive, the same water can be used for several technological operations if the water pollution degree in the previous operation is less than it is in the next one (stepwise water utilization). Thus pure or purified water is used first in those processes that in no way or only slightly pollute it, then in those that pollute it somewhat more and so on up to the maximum pollution in the course of production.

Figure 14 depicts a general stepwise water utilization scheme in the food-processing industry.

Water reusage

Because of stricter regulations relating to water pollution and the increasing consumption of fresh water, the disposal of polluted water is of growing significance. The full recycling of polluted water may at first seem an unattainable or even unnecessary goal, yet this has recently become the preoccupation of experts in the field of water technology.

Once it becomes evident that the recirculation of already used water can be less expensive than transporting water from a raw water source, industry will of necessity exploit the possibilities offered by the closed-cycle operation. Some steel mills, refineries and electric power stations, and some food-processing plants operating the year round have in fact achieved perfect closed cycles.

More and more frequently water is being reused after it has been purified to meet the quality requirements of a particular process. The decision to use this system depends on several factors:

(a) Cost of water from the source at hand, including the costs of transportation and purification.

(b) Compensation costs because of polluting the waterway receiving the discharged waste water; the waterway must be treated by subsequent users.

(c) Loss of valuable materials from the production process, which leave the plant as waste water.

(d) Waste water quality regulations imposed by the local authorities, which are very often stricter than those for industrial use.
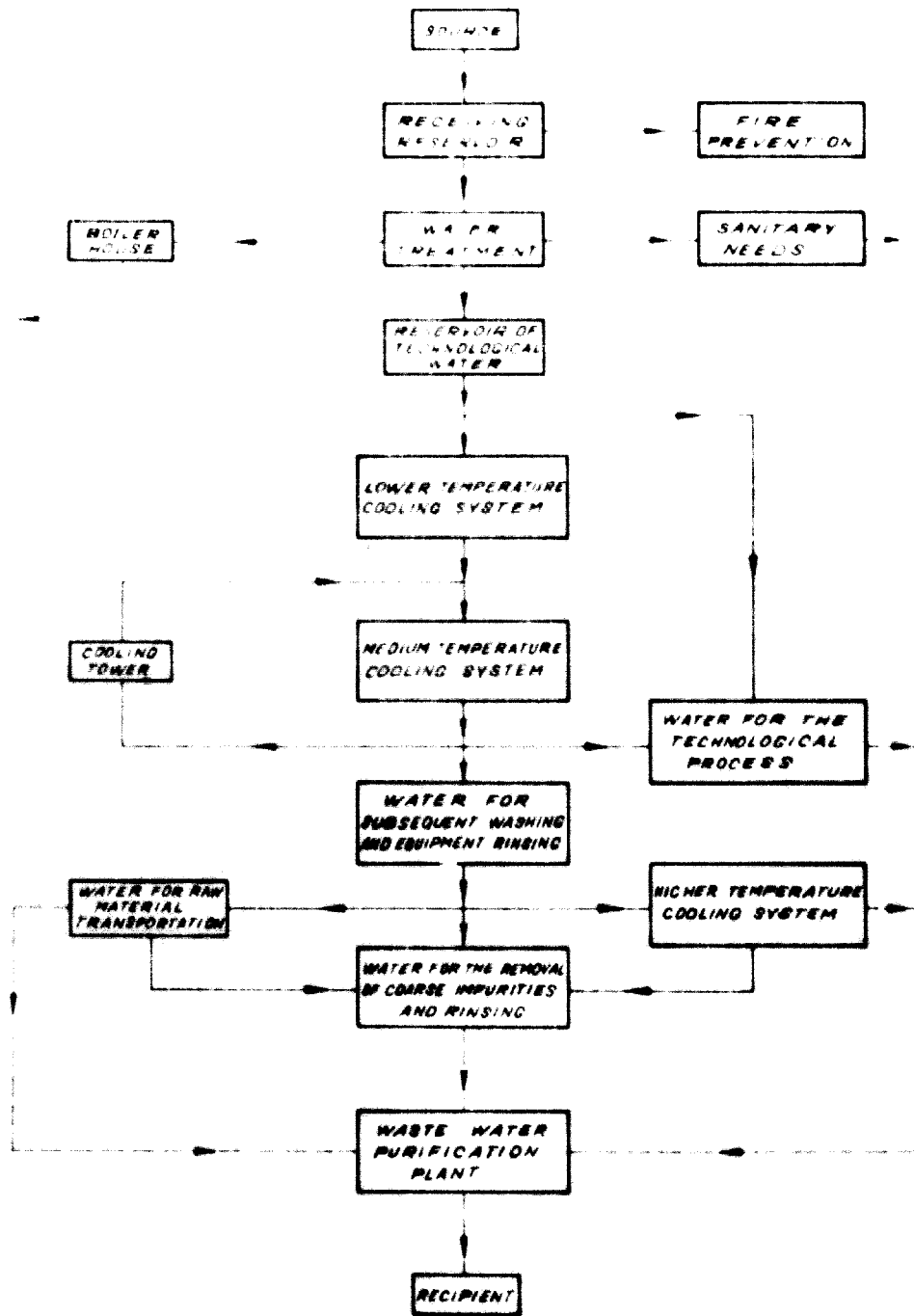
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Figure 14. The stepwise utilization of water in the food-processing industry

Cost considerations in the operation of water-purification plants

An important factor in selecting the optimum location for a factory is the possibility of securing the most economic supply of the best quality water as well as the cheapest means of discharging waste water into suitable recipients. It is important to know what concentration of waste materials the authorities will permit to be discharged into the receiving stream.
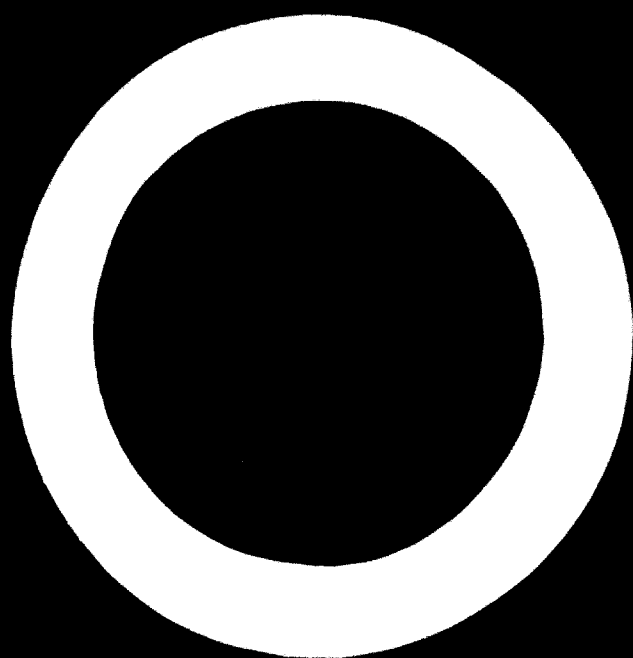
Water-treatment costs vary considerably and depend on the quality of the source water and on the quality of the water required by a particular type of production. In the same way the costs of waste water treatment depend on the degree of pollution and the purity standards enforced when the waste water is discharged into the waterway. These costs differ for each industry, and even for the same type of production when local conditions differ. The most economical purification system must be chosen, but the possibilities of future expansion, with greater water demand as well as greater quantities of polluted waste water should not be disregarded.

When industry starts to develop in regions rich in water, only the minimum standards of quality are met when waste water is discharged into the waterways. As industry develops, the once abundant supply of water becomes scarcer, and the quality of the water hauled from the waterway inferior. It is necessary to bear this in mind when considering the economics of water utilization.

Because of the comparatively high investment costs for water-purification plants it is necessary to calculate whether it is more profitable to utilize a nearby water source of poorer quality and to install a water-purification plant or to haul water of superior quality from a more distant source. Similar considerations apply with respect to waste water purification and its disposal into receiving waterways.

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