Chapter 1

Nature of turbidity and colour in water - an overview.

1.1 Introduction

The word “turbidity” means the opalescence or loss of transparency of water caused by the presence of minute suspended particles in it. Suspended matter is present in all natural waters. It may be a very small amount, as in the crystal-clear waters in caves and in some parts of the ocean, but microscopic inspection up to now has always indicated the presence of at least some suspended particulate material. Because of this ubiquitous presence, and because of the physical and chemical properties of the particulate material itself, the suspended matter forms an integral part of the worldwide geochemical, biological and geological cycles in the aquatic environment. By convention, particulate matter in suspension is defined as the material that is retained on a 0.4 to 0.5 μm pore size filter, although smaller particles are sometimes found. Smaller material is considered to be dissolved, and no upper limit has been fixed [Eisma, 1993]. Particles larger than 0.1 mm in size usually settle very rapidly unless they are present in highly turbulent waters or have very low densities. Even when present, they can be rapidly removed by filtration through sand beds. Dissolved molecules in water usually are smaller than 10 nm. Therefore particulate matter that require special treatment to be removed fall in the range from 10 nm to 0.1 mm and are of particular interest to our work. The approximate time required by particles of various sizes to settle when left
Table 1.1

Surface area and settling times for particles of different diameters

[Adapted from Powell, 1954]

<table>
<thead>
<tr>
<th>Diameter of particles (mm)</th>
<th>Examples</th>
<th>Total surface area* ( (m^2) )</th>
<th>Time needed to settle by 1 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Gravel</td>
<td>( 3.14 \times 10^{-4} )</td>
<td>1 s</td>
</tr>
<tr>
<td>0.1</td>
<td>Coarse sand</td>
<td>( 3.14 \times 10^{-3} )</td>
<td>10 s</td>
</tr>
<tr>
<td>0.01</td>
<td>Fine sand</td>
<td>( 3.14 \times 10^{-2} )</td>
<td>2 min</td>
</tr>
<tr>
<td>0.001</td>
<td>Silt</td>
<td>( 3.14 \times 10^{-1} )</td>
<td>1.8 hr</td>
</tr>
<tr>
<td>0.0001</td>
<td>Bacteria</td>
<td>( 3.14 )</td>
<td>7.5 days</td>
</tr>
<tr>
<td>0.00001</td>
<td>Colloidal particles</td>
<td>( 31.4 )</td>
<td>2 years</td>
</tr>
<tr>
<td>0.000001</td>
<td>Colloidal particles</td>
<td>( 3.14 \times 10^{2} )</td>
<td>20 years</td>
</tr>
<tr>
<td>0.0000001</td>
<td>Colloidal particles</td>
<td>( 3.14 \times 10^{3} )</td>
<td>200 years</td>
</tr>
</tbody>
</table>

*Area for particles of indicated size produced from a particle 1 cm in diameter.
undisturbed in still waters, assuming them to be perfectly spherical so as to follow
Stoke’s law, and a specific gravity of 2.65, have been calculated and are presented
in Table 1.1

Particles of a random shape, flakes etc. encounter more drag in the aqueous
medium. These and other particles of lesser density will obviously remain
suspended for a longer time. Figure 1.1 gives a comparison of the size spectrum of
various kinds of waterborne particles with the pore-sizes of various kinds of
specialised filters [Faust and Aly, 1983].

Turbidity is quantified by an optical method called nephelometry and is
expressed in nephelometric turbidity units (NTU). The method makes use of the
scattering of light by suspended particles in a direction perpendicular to the incident
beam when a strong beam of white light is passed through the suspension (Tyndall
effect). The nephelometer is calibrated against a formazine suspension prepared as
per specifications [Standard Methods, 1995] to which an arbitrary but fixed value
of turbidity is assigned.

1.2 Sources of suspended particles

The total amount of suspended matter in the rivers and lakes of the world is
estimated to be about $4.25 \times 10^8$ kg [Eisma, 1993]. Virtually all suspended matter is
supplied either by terrestrial erosion or through the production of organic matter,
biogenic carbonate and biogenic opal (amorphous silica). Volcanism supplies an
insignificant amount, but can be regionally and temporarily an important source.
Figure 1.1

Size spectrum of water-borne particles (in metres) and pore sizes of filter media

[Faust and Aly, 1983].
The mineral particles in water bodies are an assemblage of particles of different types, which reflects the rock type and weathering conditions in the source areas. Mineral particles found in suspended matter are those that are resistant to weathering. Table 1.2 indicates the composition of the principal minerals in suspended matter. In actual existence in natural waters, these may contain adsorbed constituents.

Besides mineral material, rivers transport particulate organic matter in suspension. The average organic content of suspended matter is about 4.5%. Organic matter in water bodies come from primary and secondary production in rivers and lakes, erosion from soil, human waste discharges, industrial effluents and agricultural run-offs [Eisma, 1993]. In common terminology, these include decaying animal and plant matter, humic and fulvic acids, colouring matter, pathogenic bacteria and viruses, algae, pesticides and other industrial chemicals.

1.3 Problems caused by suspended matter in water

The presence of suspended particles makes water opaque, coloured and sometimes malodourous. It thus becomes objectionable for human use by virtue of sensory quality. The opacity reduces penetration of light in water bodies and affects photosynthesis of submerged aquatic plants. The suspended matter is also a nuisance in industrial applications, affecting product quality and damaging equipment, leading to financial loss.
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Table 1.2.
Composition of minerals in suspended matter [Eisma, 1993].

<table>
<thead>
<tr>
<th>Minerals</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>SiO₂</td>
</tr>
<tr>
<td><strong>Feldspars</strong></td>
<td></td>
</tr>
<tr>
<td>Orthoclase</td>
<td>KAlSi₃O₈</td>
</tr>
<tr>
<td>Albite</td>
<td>NaAlSi₃O₈</td>
</tr>
<tr>
<td>Anorthite</td>
<td>CaAl₂Si₂O₈</td>
</tr>
<tr>
<td><strong>Clay minerals</strong></td>
<td></td>
</tr>
<tr>
<td>Kaolinite</td>
<td>Al₄(OH)₈[Si₄O₁₀]</td>
</tr>
<tr>
<td>Chlorite</td>
<td>(Al, Mg, Fe)₂(OH)₂ [(Al, Si)₄O₁₀] Mg₀(OH)</td>
</tr>
<tr>
<td>Illite</td>
<td>(K, H₂O) Al₂(H₂O, OH)₂ [AlSi₃O₁₀]</td>
</tr>
<tr>
<td>Montmorillonite</td>
<td>{(Al₂₋ₓMgₓ)(OH)₂ [Si₄O₁₀]}ₓ Naₓ · n H₂O</td>
</tr>
<tr>
<td>Calcite / aragonite</td>
<td>CaCO₃</td>
</tr>
<tr>
<td>Opal</td>
<td>SiO₂ (amorphous)</td>
</tr>
</tbody>
</table>
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The suspended particles, being very small in size, have a very large surface area per unit mass. This makes them good adsorbents and catalysts. Many poisonous chemical substances are thus adsorbed on the particle surfaces and transported over long distances. They also keep bacteria and viruses adsorbed on their surface and shield them from the effect of disinfectants applied during water treatment processes. There is almost a universal presence of coliform bacteria in surface water bodies. Thus they pose a threat to human health when drawn for domestic use.

Governing bodies of various communities have therefore made separate recommendations or specification of standards regarding maximum permissible turbidity in potable water supplied by public water supply units, and water for various industrial and recreational purposes.

1.4 Regulations regarding turbidity for drinking water supply

The WHO recommendations regarding turbidity for drinking water is as follows [Guidelines for drinking-water quality, 1993]:

"The appearance of water with a turbidity of less than 5 nephelometric turbidity units is usually acceptable to consumers, although this may vary with local circumstances. However, because of its microbiological effects, it is recommended that turbidity be kept as low as possible. No health-based guideline value for turbidity has been proposed."
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The U.S. Environmental Protection Agency (EPA) regulation [Faust and Aly, 1983] for drinking water supply is that:

1) The monthly average turbidity may not exceed 1 NTU.

2) The two-day average turbidity may not exceed 5 NTU.


1) Turbidity should be less than 1 NTU to be generally acceptable.

2) The limit may be extended up to 10 NTU in the absence of alternate sources.

1.5 Necessity for removal of suspended matter

Sand, gravel etc. settle rapidly on standing, but finer particles like silt, bacteria and plankton must be coagulated before they can be made to settle. Thus clarification of water becomes necessary for the following reasons:

1) To remove colour and odour to make water aesthetically pleasing.

2) To remove bacteria, virus etc. and make water more hygienic. Even apparently harmless suspended particles may act as vehicles for concentrating and transporting harmful pollutants.

3) To prevent formation of trihalomethanes (THM) in subsequent disinfection of the water using chlorine.

4) To make water more transparent so that photosynthesis is not affected. Thus aquatic plants and animals in ponds and aquaria may have better living conditions.
5) To meet specifications recommended for drinking water supplies and various industrial and recreational applications such as process and boiler feed waters, swimming pools etc.

1.6 Nature of colouring matter in water

The presence of various kinds of algae may impart blue, green, yellow or sometimes even reddish-brown colour to water bodies and impart a grassy, musty or even fishy odour to the water [Faust and Aly, 1983]. Apart from the presence of suspended matter as described earlier, the presence of a wide variety of water-soluble organic and inorganic compounds from various sources may also produce objectionable colour in the water. Dye-house effluents are one of the most obvious among these.

Pickling wastes and effluents from electrochemical industries and tanneries contain coloured inorganic salts of iron, nickel, chromium etc. Such inorganic material may also be leached out into water through the weathering of rocks or through volcanic activity.

But the most ubiquitous of all colouring matter present in natural water bodies is organic matter from the soil. Most surface water sources have a certain amount of organic matter of natural origin, the so-called humic substances. These compounds are degradation products of plant detritus and present in high concentrations in lake water and ground water giving the water an yellowish-brown colour [Gjessing, 1976]. These contain a large number of oxygenated functional
groups like carboxyl, phenolic and alcoholic hydroxyls, aldehydic and keto groups as well as some nitrogenous groups. These are therefore very good chelating agents and may play a role in binding and transporting heavy metals. These are also adsorbed to the surface of clay minerals.

Other sources of organic colouring matter can be agricultural run-offs, wash-water from pig, cattle and poultry farms, and effluents from breweries, tanneries and pharmaceutical industries. The coir industry in Kerala extracts fibre by soaking coconut husks (outer covering of the fruits of the palm tree Cocos nucifera) by submerging them in shallow water bodies for several months. The process is known as coir retting. Retting is based on the action of bacteria and moisture to dissolve or rot away much of the cellular tissues and gummy substances surrounding bast-fibre bundles, thus facilitating separation of the fibre [Encyclopaedia Britannica]. Natural water retting employs stagnant or slow-moving waters, such as ponds, bogs, slow streams and rivers. Water in such bodies acquire a dark brown colour from the lignaceous materials leached out from the husks, becomes highly polluted and requires treatment. Engineered tank retting is practiced now a days for greater control and better product quality.

The hue and intensity of the colour in water contaminated by such organic substances are influenced greatly by the pH conditions in the water. Conversely, their presence also considerably affects the pH of the water body.
1.7 Regulations regarding colour in drinking water supply

The WHO recommendation regarding the maximum permissible limit of colour in drinking water is as follows [Guidelines for drinking-water quality, 1993]: "Colours above 15 TCU (true colour units) can be detected in a glass of water by most people. Colours below 15 TCU are usually acceptable to consumers, but acceptability may vary according to local circumstances. No health-based guideline value is proposed for colour in drinking water."


1) Colour should be less than 5 units on the Pt-Co scale to be generally acceptable.
2) The limit may be extended up to 25 units in the absence of alternate sources.

1.8 Removal of colouring matter

The most obvious method for removing all types of colouring matter from water is adsorption by granular activated carbon (GAC) or powdered activated carbon (PAC). The method is usually very expensive and removal of the adsorbed material can become a problem especially when PAC is used. Since the organic matter gets easily adsorbed to the suspended particulate matter (including PAC), their removal by flocculation and settling can be cost effective.
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### Table 1.3.

Commonly used coagulants and flocculants [Kemmer, 1979].

<table>
<thead>
<tr>
<th>Common name</th>
<th>Formula</th>
<th>pH of 1% soln.</th>
<th>Physical form</th>
<th>Availability of active constituent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alum</td>
<td>Al$_2$(SO$_4$)$_3$. 14 H$_2$O</td>
<td>3.4</td>
<td>Lump</td>
<td>17% Al$_2$O$_3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liquid</td>
<td>8.5% Al$_2$O$_3$</td>
</tr>
<tr>
<td>Lime</td>
<td>Ca(OH)$_2$</td>
<td>12</td>
<td>Lump</td>
<td>&gt; 90% CaO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Powder</td>
<td>93 to 95% CaO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Slurry</td>
<td>15 to 20% CaO</td>
</tr>
<tr>
<td>Ferric chloride</td>
<td>FeCl$_3$. 6 H$_2$O</td>
<td>3 to 4</td>
<td>Lump</td>
<td>20% Fe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liquid</td>
<td>20% Fe</td>
</tr>
<tr>
<td>Ferric sulfate</td>
<td>Fe$_2$(SO$_4$)$_3$. 3 H$_2$O</td>
<td>3 to 4</td>
<td>Granular</td>
<td>18.5% Fe</td>
</tr>
<tr>
<td>Copperas</td>
<td>FeSO$_4$. 7 H$_2$O</td>
<td>3 to 4</td>
<td>Granular</td>
<td>20% Fe</td>
</tr>
<tr>
<td>Sodium aluminate</td>
<td>Na$_2$Al$_2$O$_4$</td>
<td>11 to 12</td>
<td>Flake</td>
<td>46% Al$_2$O$_3$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liquid</td>
<td>2.6% Al$_2$O$_3$</td>
</tr>
</tbody>
</table>
1.9 **Conventionally used coagulants and flocculants**

A list of conventionally used coagulants are given in Table 1.3 [adapted from Kemmer, 1979] along with their chemical composition and important properties.

1.10 **Mechanism of action of coagulants**

Particles in most natural waters acquire a negative charge because of the negatively charged phenolic, carboxylic acid and sulfonic acid groups present on the adsorbed lignins, tannins, humic acids, detergents etc. and functionality present on bacterial cell walls. All particles have the same type of charge, hence they repel each other and do not aggregate.

There are two layers of ions around the particle. One is at the surface of the particle itself. This is a dense layer of positive charges collected from the surrounding medium (since the negatively charged particles attract positive charges towards them) and is called the Stern layer. It is a rigid layer and supposed to move constantly along with the particles through the medium (see Figure 1.2) This layer then attracts and maintains a diffuse layer of negative charges from the medium, called the Guoy-Chapman layer. Since the particle surface is charged and the bulk of the medium is neutral, there is a potential difference between the surface and the bulk medium some distance away from it. The potential difference between the Stern layer and the bulk medium is called the Nernst potential and that between the Guoy-Chapman layer and the bulk medium is called the Zeta potential.
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Figure 1.2.
Charge distribution around a suspended particle

Figure 1.3.
Compression of charged layers by highly charged cations
- Illustration of Hardy-Schulze rule.
Measurement of the Zeta potential is important in the study of kinetics of coagulation.

The charge and concentration of the counterions in the Stern layer help to reduce the effect of the surface charge and therefore reduce the repulsion between the particles. Generally, the only positive counterion obtainable from water molecule is the hydronium ion, which is present only in very low concentrations at neutral pH. If the water contains dissolved salts, the cations derived from them enter the Stern layer and provide a more effective neutralisation of the surface charge. This tends to bring the particles closer to each other and form aggregates. Thus addition of salts like NaCl can induce coagulation of suspended matter in water.

If the counterions are di- or trivalent cations, the effect on the neutralisation of surface charge is doubled or tripled, leading to more effective coagulation using lower concentrations of added metal salts. This is known as the Schulze-Hardy rule (see Figure 1.3). This is the reason why salts of trivalent metal ions such as iron and aluminum are used as coagulants in water treatment plants.

At least four distinct mechanisms of colloid destabilisation exist [Faust and Aly, 1983]. These are (1) compression of the double-layer, (2) neutralisation of charges by adsorption of counter-charged ion, (3) entrapment in a precipitate and (4) adsorption and inter-particle bridging by the adsorbate.
Figure 1.4
Coagulation curves for various types of coagulants.

[Faust and Aly, 1983]
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Compression of the double-layer:

When addition of an electrolyte (metal salt) causes no specific interaction between it and the particle, these counterions enter into the double layer and determine its nature. The double layer thickness will decrease, and the Nernst and Zeta potentials will decrease. Particles can come closer to each other, and if a sufficient amount of an "indifferent" electrolyte is added, coagulation occurs. This effect increases greatly as the valence of the counterion increases (Schulze-Hardy rule). That is, a lesser concentration of trivalent ion will bring about coagulation than a divalent ion, which in turn requires a lesser concentration compared to a monovalent ion. (See Figure 1.4 'a').

Adsorption and charge neutralisation:

Colloidal suspensions of negatively charged silver iodide particles can be coagulated using dodecylammonium ions \((C_{12}H_{25}NH_{3}^+)\). On the basis of electrostatic models, this monovalent cation should induce coagulation in a manner similar to \(Na^+\) ions. But when about a decimole of \(Na^+\) is required for coagulation, about \(6 \times 10^{-5}\) moles of the organic amine is effective. This suggests a coagulation mechanism in addition to electrostatic interaction. Further, addition of more of the organic amine was found to cause a restabilisation of the colloid accompanied by charge reversal. This can be explained by an adsorption of excess of amine on the colloid particle. (See Figure 1.4 'b').
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Entrapment in a precipitate

Colloidal silver iodide can be coagulated using a low dosage of $6 \times 10^{-6}$ moles of aluminum nitrate. The colloidal system was restabilised and the charge reversed at higher dosages of about $4 \times 10^{-5}$ moles. On increasing the concentration further, there is another zone of coagulation at still higher doses of about $10^{-2}$ moles where Al(OH)$_3$ is precipitated (see Figure 1.4 ‘c’). In this second region of coagulation, the coagulant is precipitated rapidly, floc is formed, and an interaction occurs with the colloid. This is frequently called “orthokinetic coagulation” or the “sweep floc” formation. It is the entrapment of a low zeta potential colloid within a precipitate. The coagulants Al(OH)$_3$, Fe(OH)$_3$, etc. physically destabilise the colloid.

Adsorption and inter-particle bridging

There has been a large increase recently in the use of synthetic organic polymers as coagulants or as coagulant aids. These are effective at very low concentrations (see Figure 1.4 ‘d’). Neutral or even anionic polymers are sometimes found to be very effective. Obviously, an electrostatic mechanism is not able to explain these observations. A “bridging” mechanism was proposed by La Mer and Healy to account for destabilisation of colloidal systems by high molecular weight organic polymers.
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Figure 1.5

The bridging mechanism of coagulation.

[Faust and Aly, 1983]
In order for a polymer molecule to act as an effective destabiliser, it must contain constituents that can interact with sites on the colloidal particle. The attachment of the polymer to the particle may lead to coagulation. The unattached portion of the polymer can interact with a second particle, forming a bridge between the particles. Longer the polymer chain, larger will be the number of particles incorporated (see Figure 1.5). This may also lead to coagulation and an increase in the mass and density of the floc. A third possibility is that bridging may not occur, the entire polymer chain may surround the particle, leading to stabilisation of the particle. This type of restabilisation is not due to charge reversal in the case of an anionic polymer, but may be due to saturation of the particle’s surface with excess polymer. Further, extended rapid agitation of the floc may lead to rupture of the bridge, fragmentation of the floc and possible restabilisation.

1.11 Kinetics of particle aggregation

Flocculation and coagulation of colloids, by whatever mechanism, depend on the frequency of collisions and on the efficiency of particle contacts. Whenever suspended particles collide, there are at least three mechanisms of transport bringing the particles together [Stumm and Morgan, 1981].

1. Particles are in motion because of their normal energy (Brownian motion). Any coagulation occurring by this means is called “perikinetic coagulation.”
2. When the particles are large enough, or when the fluid shear rate (stirring rate) is high enough, the relative motion from velocity gradients exceeds that by thermal effects. This is called "orthokinetic coagulation."

3. In the sedimentation process, particles with different gravitational settling velocities may collide and aggregate.

### 1.12 Desirable characteristics in the flocs produced

1. Floc density – dense flocs settle fast.
2. Shear resistance – this is required to prevent breakage of flocs during stirring.
3. Filterability – good filterability is desirable for fast and complete removal of flocs.
4. Compressibility – good compressibility is desirable to reduce sludge volume.

### 1.13 Coagulant aids

Flocs formed by hydrolysed metal coagulants may not have all the aforementioned desirable characteristics. Coagulation may also become difficult in the presence of interfering substances. Therefore coagulant aids are sometimes used to aid primary coagulants. These are usually polyelectrolytes or activated silica.

### 1.14 Polyelectrolytes used in coagulation

These are synthetic organic linear or branched polymers of high molecular weight. If the monomer contains an ionisable group such as carboxyl, amino or sulfonic, then the polymer is called a polyelectrolyte. There are cationic, anionic or
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(1) Nonionic polymers:

\[
\begin{align*}
\text{Poly ethyleneoxide (PEO)} & : \left( \begin{array}{c}
\text{CH}_2 - \text{CH}_2 - \text{O} \\
\end{array} \right)_n \\
\text{Poly acrylamide (PAM)} & : \left( \begin{array}{c}
\text{CH}_2 - \text{CH} - \\
\text{CO} \\
\text{NH}_2 \\
\end{array} \right)_n
\end{align*}
\]

(2) Anionic polyelectrolytes:

\[
\begin{align*}
\text{Poly acrylic acid (PAA)} & : \left( \begin{array}{c}
\text{CH}_2 - \text{CH} - \\
\text{CO} \\
\text{O}^- \\
\end{array} \right)_n \\
\text{Poly styrene sulphonate (PSS)} & : \left( \begin{array}{c}
\text{CH}_2 - \text{CH} - \\
\text{SO}_3^- \\
\end{array} \right)_n
\end{align*}
\]

(3) Cationic polyelectrolyte:

\[
\begin{align*}
\text{Poly diallyl dimethyl ammonium} & : \left( \begin{array}{c}
\text{HC} - \text{CH}_2 - \text{CH} - \text{CH}_2 \\
\text{H}_2\text{C} - \text{N}^+ - \text{CH}_3 \\
\text{H}_3\text{C} \\
\end{array} \right)_n
\end{align*}
\]

(PDADMA, Cat-Floc)

Figure 1.6.

Commercially available synthetic polymeric flocculants
ampholytic (having both positive and negative groups) polyelectrolytes. Nonionic polymers are those without any ionisable groups. Some examples are presented in Figure 1.6 (Faust and Aly, 1983).

The use of high-molecular mass organic compounds as flocculants is not a new development. Many natural organic materials such as starch, cellulose, polysaccharide gums and proteins have been used as flocculant aids. Synthetic polyelectrolytes are relatively more expensive and their use is warranted only for specialized applications.

1.15 Jar Tests

The famous jar testing method developed by Cohen is extensively used for quality control of in-plant coagulation process. It is an extremely useful technique for determining parameters such as coagulant dosage, pH, alkalinity and flocculation time, but is not particularly useful for scaling up information.

Jar test results correlate reasonably well with plant tests. They are significant for a number of quality control techniques for the coagulation – filtration process. These are: time required for the appearance of first floc, visual evaluation of floc size, rate of settling of floc, visual or photometric measurement of supernatant or filtrate clarity and colour, and analytical determination of residual coagulant in the supernatant or filtrate. In-plant and continuous monitoring of turbidity is an extremely useful quality control technique for determining the optimum coagulant dosage.
1.16 Disposal of coagulation sludges

Direct discharge of sludges from coagulation process into water bodies is undesirable. In many countries this type of disposal is forbidden. Alum sludge is a non-Newtonian, bulky and gelatinous material. It is composed of hydrous aluminum oxide and other inorganic particles such as clay, sand or carbon, and organics such as colour colloids, waste particulates and various types of microorganisms. The total solid content is variable, but is in the range of 1 to 20 g L\(^{-1}\) of which 75 to 90% are suspended solids. Alum sludges tend to have neutral pH values. These sludges are readily settlable. But they are very difficult to dewater, have low solid content and large sludge volumes, which make them difficult to handle and subsequently place in a landfill. They tend to accumulate at the site of disposal and may be of concern to the public in relation with Alzheimer’s disease [Stauber et. al., 1999].

1.17 Necessity for developing new flocculants

From the facts discussed above it is apparent that better flocculants have to be developed, which should have several or all of the following desirable characteristics:

1. They must be easily available locally or manufactured from cheap raw materials.

2. They should be cost effective for continuous application on a large scale.
3. They should be very effective at a very low dosage and should not alter the pH of water considerably from the neutral, so that further corrective treatment is not necessary.

4. The residual concentrations of the flocculant in the treated water must be very low or negligible.

5. If at all present, the residual must be non-toxic to man and to aquatic organisms.

6. They should be biodegradable and should not accumulate at the site of disposal.

7. They should be able to remove most or all of the undesirable substances present in the water.

8. They should initiate flocs that grow very rapidly to a large size. This will make processing faster.

9. The sludge produced should be very dense and settle rapidly. This will lead to smaller treatment plants and lower operating costs.

10. The sludge collected should be easy to dewater, have a high solid content and low sludge volume. This makes storage, transport and disposal of the sludge economically viable.