INVESTIGATION OF FLOCCULENT-FLOCS IN A MULTILAYER-FLOATING-MEDIA FLOCCULATOR USING HIGH RESOLUTION IMAGES

INTRODUCTION

Flocculation is a common process used in water and wastewater treatment plants. It also affects the behavior of particles in a natural system. Factors affecting this process include coagulant type and dose, solution pH, mixing intensity and particle concentration. Flocculation is a very important step in many solid-liquid separation processes and the structure of flocs can greatly influence the efficiency of separation.

Floating plastic media is a hydraulic flocculator/prefilter that induces floc formation by using a continuous flow of coagulated water through porous media and separating floc and particle by filter bed (Schulz *et al*., 1994). The advantages of floating-media is a reduction in the capital cost of the treatment facility as a result of elimination of the settling basis and elimination or significant reduction of the flocculation tank (Ben Aim *et al*., 1993), high treatment efficiencies, automated operation, limited space requirements, which is especially important in an intensively urbanized area where land is limited for installing a new facility (Innerfeld *et al*., 1979). Other benefits include a reduction in chemical flocculent dosage, resulting in decreased sludge production and less maintenance (Ben Aim *et al*., 1993).

Microscopic analysis is often difficult to measure accurately using existing technologies. It requires samples to be withdrawn and the particle to be passed through a small orifice, which may cause the floc to break apart and disperse (Gibbs, 1982). Since the flocs break up easily during sampling and handing (Eisma, 1986), in-situ or optical technique are necessary to avoid these problems (Gibbs, 1982). Natural flocs have been studied up to now only by direct observation in the water. In-situ photography has yielded some information on size and shape of the floc, but reliable size distributions have not yet been obtained, mainly because the technique of size analysis of floc in-situ has not yet given quantitatively reliable results for the whole size range (Eisma, 1986).

Therefore, the structure of this research “Investigation of Flocculent Flocs in Multilayer-Floating-Media Flocculator Using High Resolution Images” has been separated into 3 parts. Firstly; the optimum condition was determined of Polyaluminium Chlorides (PACl) dose and hydraulic rate. Secondly; the performance of the system was investigated in terms of large and rapid settling floc production using digital camera visualization. Thirdly; the comparison between the floc size measure by a microscope analysis (d_M) and floc size analyzed by digital image analysis (d_D) was carried out.

OBJECTIVE

The objectives of this study were classified as follows:

1. To apply the technique of digital camera visualization for analyzing flocculent-flocs size in a multilayer-floating-media flocculator and to compare the results between the conditional method of microscopy and digital visualization.

2. To determine the optimum operating parameters such as media size, depth of media-layer, hydraulic rate and flocculent dose for production of large and rapid flocs settling.

SCOPE OF THE STUDY

1. A digital camera (FinePix S5000, FUJI) was used to take images of flocculent-flocs produced in the floating-media flocculator. Images of flocculent-floc were analyzed using image analysis programs. The analytical results from digital camera images were compared with the floc size analysis using the microscopy during which the flocculent-flocs were sampled and plated on a glass slide in wet condition and then were observed with the microscope.

2. The optimum operating parameters were determined at different media size such as 3, 6, and 10 mm in diameter, depth of media layer such as 30 and 60 cm, hydraulic rate such as 2.5, 5, and 10 m^3/m^2-h, flocculent doses (Polyaluminium Chlorides : PACl) such as 1.25, 2.5, 5, 10, and 40 mg/L. The synthetic raw water was prepared by dissolving kaolin-clay in tap water to produce a sample with a turbidity of 80 NTU, approximately. The experimental parameters consisted of floc size, floc density, settling velocity, turbidity, pH, temperature, head-loss development.

LITERATURE REVIEWS

Colloid

Colloid is turbidity or suspended solids size as 10^{-6} to 10^{-3} mm. Effect to colloid was small and low weight until unable sedimentation small until unable to sediment by them self on define time such as suspended floc in raw water has difference size and filtration that use to separate floc. In general, a colloid or colloidal dispersions, is a two-phase system of matter, small droplets or particles of one substance, the dispersed phase, are dispersed in another, continuous phase forming so called phase colloid. Another type of colloid is called molecular colloid and is formed of macromolecules dispersed in a continuous phase (dispersion medium). Many familiar substances, including butter, milk, aerosols asphalt, inks, glues and sea foam, are colloids (T.Graham, 1864). Colloids can be classified as follows:

Table 1 Classification of colloids

		Dispersed phase		
		Gas	Liquid	Solid
Continuous Phase	Gas	None: all gases are soluble	Liquid aerosol, Examples: fog, mist	Solid aerosol, Examples: Smoke, dust
	Liquid	Foam, Examples: Whipped cream	Emulsion, Examples: Milk, mayonnaise, hand cream, blood	Sol, Examples: Paint, pigmented ink
	Solid	Solid foam, Examples: Aerogel, Styrofoam, Pumice	Gel, Examples: Gelatin, jelly, cheese, Opal	Solid sol, Examples: Cranberry glass, Ruby glass

Source: Tipler and Paul (2004)

Coagulation

Coagulation (Destabilization) is the physical-chemical change that occurs between the soluble coagulant and the alkalinity in water to form precipitated or incipient floc. Coagulation includes feeding one or more chemicals to water and rapid mixing to disperse the chemicals. During mixing, or thereafter, chemical reactions occur, resulting in destabilization of colloidal and fine suspended solids and initial aggregation of destabilized particle (Cheremisinoff, 1995). Destabilization can be created by four processes (Ravina and Moramarco, 1993).

1. Double layer compression

Double layer compression involves the addition of an ionic compound to water. The change in ionic concentration compresses the double layer around the colloid. This mechanism is often called salting out.

2. Charge neutralization

Charge neutralization refers to the adsorption of a positively charged coagulant (such as alum) on the surface of the colloid. This positive charge neutralizes the negative charge of the colloid, resulting in a near zero net charge. Charge neutralization can be controlled by using zeta potential. This is important because overdosing can reverse the charge on the colloid, and redisperse it as a positive colloid, resulting in poor flocculation.

3. Interparticulate bridging

Bridging occurs when long-chain polymers which carry negative charges attach to colloids, capturing and binding them together. Bridging is often used in conjunction with charge neutralization to form fast settleable floc. For example, alum (low molecular weight cationic polymer) is first added under rapid mixing conditions to lower the charge and allow microflocs to form. Then a small amount of high molecular weight anionic polymer is added to bridge between the microfloc.

4. <u>Colloid enmeshment</u>

Colloid enmeshment refers to the adding of excessive doses of coagulants, usually aluminum or iron salts which precipitate as insoluble metallic hydroxides, $Al(OH)_3$ or $Fe(OH)_3$. The negative colloids are swept from the water by enmeshment in the settling hydrous oxide floc. This mechanism is often called sweep coagulation.

<u>Coagulant</u>

The coagulant can be separated into main 3 classes.

1. **<u>Aluminium salts</u>** such as

   Aluminium sulfate or alum: $Al_2(SO_4)_3.14.3H_2O$

   Ammonia alum: $Al_2(SO_4)_3(NH4)_2 SO_4.24H_2O$

   Potash alum: $Al_2(SO_4)_3K_2 SO_4.24H_2O$

2. **<u>Iron salts</u>** such as

   Copperas: $FeSO_4.7H_2O$

   Chlorinated copperas: $FeSO_4.7H_2O + Cl_2$

   Ferric chloride: $FeCl_3$

   Ferrifloc: $Fe_2(SO_4)_3$

3. **<u>Others</u>** such as

   Sodium aluminate: $NaAlO_2$

   Polyaluminium chloride: PACl

Different chemicals substance may be used in coagulation depending on the characteristic of water being treated. In some water, the combination of two or more chemicals is better than one chemical alone. It is usually necessary to perform coagulation tests (jar test) in laboratory to decide which chemicals should be used.

Chiemchaisri *et al*., (2003) reported that the appropriate filtration rate of using combined floating plastic media (polypropylene) with sand for surface water treatment was 5 m^3/m^2-h, by comparison between PACl, alum and $FeCl_3$. Polyaluminium chloride was found to be the best coagulant which achieved the average suspended solids removal efficiency and average turbidity removal efficiency of 95.5% and 96.3%, respectively.

Polyaluminium chloride (PACl)

Polyaluminium chlorides (PACl) are synthetic polymers that dissolve in water. They react to form soluble aluminium poly-hydroxides which precipitate in bigger volumetric flocs. PACl can be used as a coagulant for all types of water treatment such as drinking water, industrial wastewater, urban wastewater (ENCO Engineering, 2003).

The advantages of PACl consist of

- lower dosage requirement
- no requirement for a neutralizing agent (such as soda, lime)
- shorter flocculation time
- smaller amount of sludge
- reduced number of backwashing step
- higher quality of the treated water
- forming quickly settle floc
- wide range pH variation

Flocculation

Flocculation refers to the gentle agitation of treated water for a period of time. The mechanism occurring in this step is the collision of the small floc particles with each other and with other suspended particles in the water. This occurrence causes them stick together or agglomerates and grow into large floc masses and readily settleable masses. (Cheremisinoff, 1995)

There are three physical processes acting transport particles and increase particle-particle interaction, enhancing the likelihood of coagulation and flocculation: perikinetic flocculation (Brownian diffusion), orthokinetic flocculation (fluid shear), and differential settling. (Blazier, 2003). A diagram of these processes is shown in Figure 2.

1. Perikinetic flocculation

Perikinetic flocculation is the result of collisions of the small particles due to Brownian motion. This motion is induced by the temperature of the water. This process occurs when the diameter of the particles is less than 1 micron, so it does not help to grow larger floc. This results in a "micro-floc"

2. Orthokinetic flocculation

Orthokinetic flocculation is the growth of the particles due to fluid motion (agitation). This process produces the bulky separable floc needed for clarification by sedimentation or filtration.

3. Differential settling

Differential settling occurs when particles settle due to gravity and collide with other particles forming flocs during vertical transport.

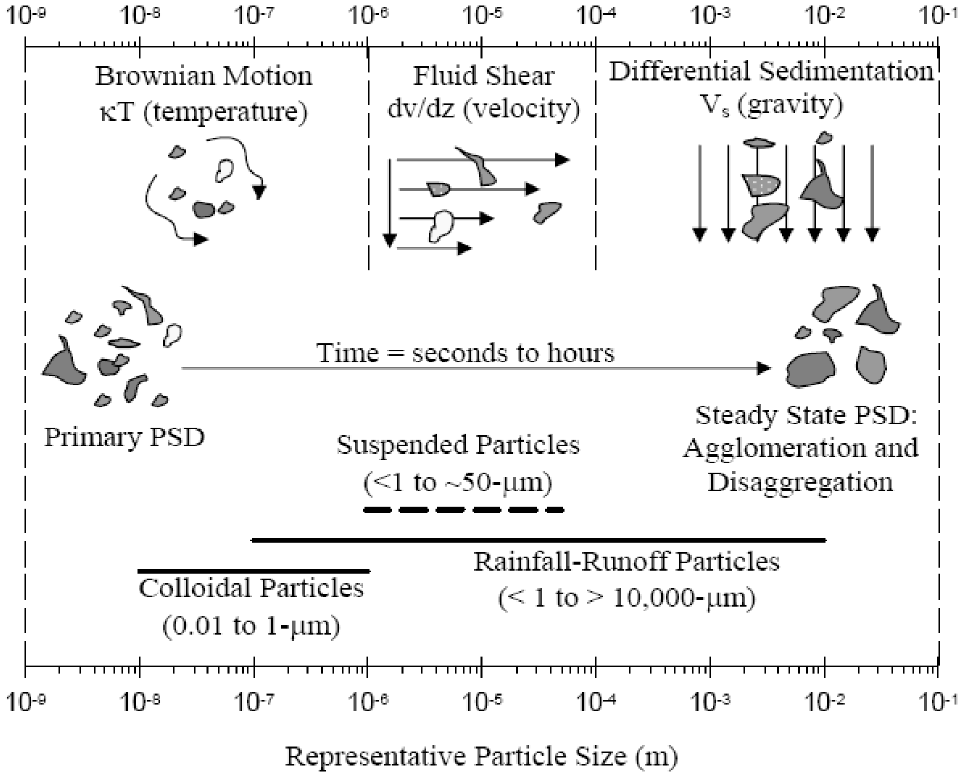

Figure 1 Conceptual schematic of the sub-processes controlling particle aggregation, the size spectrum for naturally occurring rainfall-runoff particles

Source: Blazier (2003)

The agitation in flocculation can be induced by mechanical flocculators such as paddles, propellers, turbines etc. or hydraulic flocculators such as baffle channels, coarse media etc. Schulz *et al*., (1994) evaluated the new development of coarse media flocculator that used floating or buoyant plastic media in the laboratory and field. The study reported that two-stage buoyant media flocculator had advantages such as effective treatment at higher loading rate and shorter residence time than mechanical flocculators.

Principle of Floating Plastic Media

In conventional water treatment system, coagulation and flocculation are usually followed by sedimentation and filtration for elimination the fine suspended solids and colloidal solids in water and disinfection for killing pathogens. However, the system requires facilities that involve the high cost of construction, operation and maintenance. Consequently, the development of water treatment process requires a compact and less energy consumptive system when the system performance is compared with the conventional processes. Therefore, this research is related to the new development of compact and economic process, or referred to floating plastic media flocculator.

The floating plastic media flocculator was developed from contact-flocculation filtration, a process whereby coagulant is added directly to the raw water. After that both flocculation and filtration occur within the filter bed itself (Kawamura, 1991). A diagram of contact-flocculation filtration is shown Figure 2. The typical media filter used in contact-flocculation filtration is composed of sand, anthracite, gravel and etc. The drawbacks of these heavier media are high energy consumption for backwashing, high clogging, intermixing of again after backwashing, and high head loss development (Lager *et al*., 1977). These lead to the new improvement on buoyant or floating plastic media by many researchers (Ngo and Vigneswaran, 1995a, 1995b; Schulz *et al*., 1994; Visvanathan *et al*., 1996).

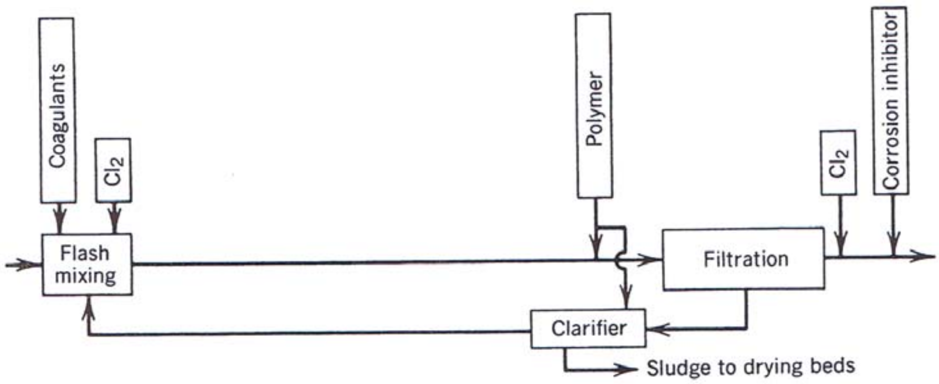

Figure 2 Contact flocculation-filtration process

Source: Kawamura (1991)

Numerous floating plastic media flocculators have been tried in water and wastewater treatment. The experiment (using polypropylene bead of depth 16-40 cm) produced the uniform microfloc (26-40 μm), low head loss development (3 cm in 4 hours) and increased removal efficiency when operating at higher media depth and lower filtration rate (Ngo and Vigneswaran, 1995a). The result from the experiment using combined system between floating plastic media and coarse sand filter unit compared with single floating plastic media showed that the combined system increased removal efficiency (more than 87% and 94% of NH_3-N and total-P removal, respectively), especially at low filtration rate: 5 m^3/m^2-h (Ngo and Vigneswaran, 1995b).

In addition, Visvanathan *et al*., (1996) did experiments with coarse polypropylene and fine polystyrene as dual floating media filter. The results from the study showed that the advantages of dual floating media filter was higher turbidity removal per unit head loss than sand filter, lower head loss development, higher retention capacity, solving the problems of intermixing and eliminating the need for an elaborate underdrain system causing a reduction of capital, operating and maintenance costs.

The floating plastic media is a hydraulic flocculator that induces floc formation by using continuous flow of coagulated water through the pores of media and separating floc and particle by filter bed. In floating plastic media, floc is retained in the porosity of the media, decreasing void and promoting more contact between small particle and subsequent flow water. Tapered flocculation is achieved by grading the bed of different size or changing in cross-section area. There are three major processes involving in the floating plastic media: coagulation, flocculation and filtration (Schulz *et al*., 1994).

Mechanisms of Solid Removal in Granular Medium-Depth Filter

Conventional filtration is the separation of solid particles from a liquid by passing through a medium, such as sand, anthracite coal, activated carbon and etc. After that filter retains the solid on its surface and allows the liquid to pass through.

Table 2 Principal mechanisms and phenomena contributing to removal of material with in granular medium-depth filter

Mechanism/phenomenon	Description
1.Straining	
a. Mechanical	Particles larger than the pore space of the filtering medium are strained out mechanically
b. Chance contact	Particles smaller than the pore space are trapped within the filter by chance contact
2.Sedimentation	Particles settle on the filtering medium within the filter
3.Impaction	Heavy Particles will not follow the flow streamlines
4.Interception	Many particles that move along in the streamline are removed when they come in contact with the surface of the filtering medium
5.Adhesion	Particles become attached to the surface of the filtering medium as they pass by. Because of the force of the flowing water, some material is shared away before it become firmly attached and is pushed deeper into the filter bed. As the bed becomes clogged, the surface shear force increases to a point at which no additional material can be removed. Some material may break through the bottom of the filter,

Table 2 (Cont'd) Principal mechanisms and phenomena contributing to removal of material with in granular medium-depth filter

Mechanism/phenomenon	**Description**
5.Adhesion (cont'd)	causing the sudden appearance of turbidity in the effluent
6.Flocculation	Flocculation can occur within the interstices of the filter medium. The larger particles formed by the velocity gradients within the filter are then removed by one or more of the above removal mechanisms.
7.Chemical absorption a. Bonding b. Chemical interaction 8.Physical absorption a.Electrostatic forces b.Electrokinetic forces c.Van der waals forces	Once a particle has been brought in contact with the surface of the filtering medium or with other particles , either one of these mechanisms, chemical or physical absorption or bath, may be responsible for holding it there
9.Biological growth	Biological growth within the filter will reduce the pore volume and may enhance the removal of particles with any of the above removal mechanisms[1 through 5]

Source: Metcalf and Eddy (2003)

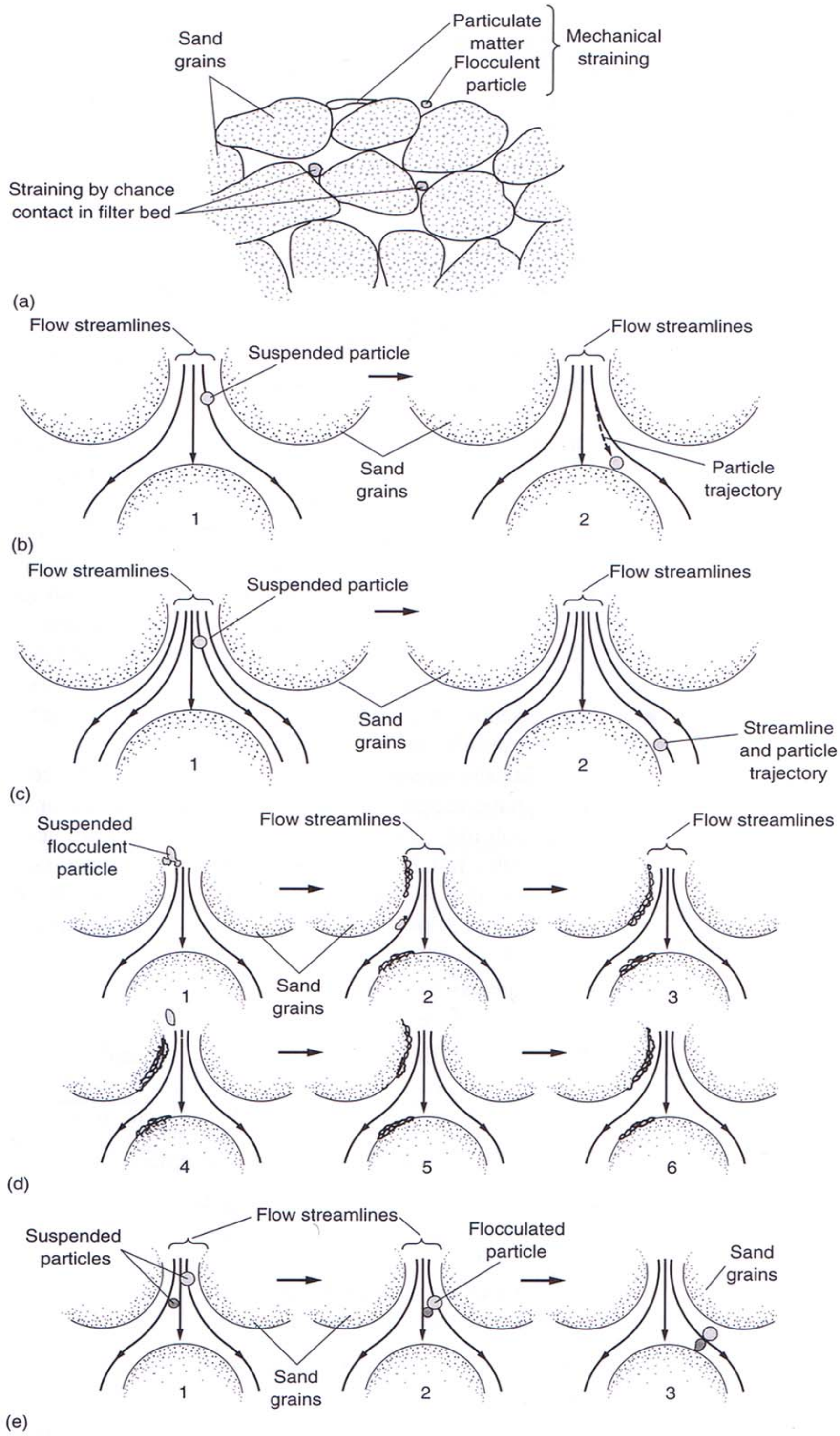

Figure 3 Removal of suspended particle matter with in a granular filter (a)by straining (b) by sedimentation or inertial impaction (c) by interception(d) by adhesion (e) by flocculation.

Source: Metcalf and Eddy (2003)

Direct Filtration and Contact-Flocculation Filtration

Direct filtration process refers to the filtration without sedimentation. In this process, coagulated water containing destabilized particle is directly fed through the filter bed. The agglomeration of particle to form visible floc occurs from the number of opportunities for collision of particle in porous media. After that floc is separated by attachment or adsorption to surface of filter grain. This mechanism defines as contact-flocculation filtration. (Culp, 1977)

Luttinger (1981) concluded that the direct filtration process required the pin point floc (small-dense floc) more than large floc (sweep floc). This strength floc was allowed to well penetrate into the deeper filter zone resulting in the full storage capabilities of filter grain and longer filter run. This manner corresponded to the finding of Kludpiban (2000). She studied the turbidity removal by using Floating plastic media process. The experiment used $FeCl_3$, Alum, PACl like coagulant at 20%, 40% and 60% of optimum dose obtained by Jar test. Polyalumimium chloride represented the best efficiency for both turbidities of 20 and 40 NTU at 20% of optimum dose obtained by Jar test. At the turbidity of 20 NTU, this dose achieved the short term and long term turbidity removal efficiency of 96.8% and 81.8%, respectively. At the turbidity of 40 NTU, this dose achieved the short term and long term turbidity removal efficiency of 97.7% and 94.6%, respectively.

Particle size and shape

Particles in the water may range in size from a few nanometers (macromolecules) up to millimeters dimensions (sand grains). Natural particles also have various shapes, including rods, plates, and spheres, with many variations in between, which make treatment of a particle size difficult. The discussion is vastly simplified if the particles are considered to be spherical. In this case, only one size parameter is needed (the diameter) and hydrodynamic properties are much more easily treated. Of cause, nonspherical particle are of great importance in natural water and some way of characterizing them is essential. A common concept is that of the equivalent sphere, base on a chosen property of the particles.

For instance, an irregular particle has a certain surface area and the equivalent sphere could be chosen as that having the same surface area. The surface area of a sphere, with diameter d, is just ¶d^2. So, if the surface area of the nonspherical particle is known, the equivalent sphere diameter can easily be calculated. For an object of a given volume, the sphere has the minimum surface area and so the volume (or mass) of a particle must be equal to or less than that of the equivalent sphere. Another common definition of equivalent spherical diameter is based on sedimentation velocity. In this case, from the sedimentation velocity and density of a particle, the diameter of a sphere of the same material that would settle at the same rate can be calculated. This is sometimes called the "Stokes equivalent diameter".

Measurement of particle size

There are many approaches to the problem of determining particle size and a large number of commercial instruments, based on various techniques. There is no universal method applicable over the whole size range, and choices have to be made, depending on the nature of the suspension. In determining particle size it is very convenient to report the result in term of a single parameter such as an "equivalent diameter", although, for nonspherical particles, this gives no indication of the true shape. Mostly, we just have to accept that reported particle sizes are subject to this limitation.

Microscopy

One of the oldest and still the most direct methods of determining particle size is by microscopic observation. A sample of suspension can be viewed at an appropriate magnification and individual particles can be sized, using a suitable scale or by an automated image analysis method. Optical microscopy is limited by the wavelength of visible light, so that particles smaller than around 1 μm are difficult to resolve. In fact, reliable particle sizes cannot be derived for particles smaller than about 5 μm. It is possible to use dark-field illumination (ultramicroscope), by which particles are seen as pointes of light against a dark background. This is essentially a light scattering method and allows small particles to be resolved, although reliable sizing is difficult.

Particle counting and sizing

Automated particle counting can be achieved by allowing particles to pass singly through a zone in which their presence can be detected by a suitable sensor. Passing through the zone produces a response from the detector and can be counted as a series of pulses. If the sensor response depends on particle size, then the pulse height is size-dependent and this provides a means of discriminating between particles of different sizes. It is important to ensure that particles do not pass simultaneously through the sensing zone; otherwise two or more particles would produce just one pulse and would be counted as one (larger) particle. This is known as the coincidence effect, and, although statistical correction for this effect is possible, the most satisfactory procedure is to ensure that sample is sufficiently dilute to avoid the problem. For many suspensions of interest, high degrees of dilution are necessary, which may cause some change in the particle size distribution, especially for aggregating particles. There are two commonly used detection techniques in particle counting: electrical and optical, giving electrical sensing zone (electrozone) and optical sensing zone (light scattering) counters. The two types have their own advantages and disadvantages.

The Coulter technique has been used widely, with thousands of references in literature. It is capable of high-speed counting (5000 or more particles per second) and can resolve particles only slightly different in size. The most common use of this technique has been for rapid counting of blood cells. A unique feature of the electrozone method, in comparison with other (especially optical) techniques, is that it is virtually independent of the shape or composition of the particles. A particle passing through the orifice gives a pulse that depends only on the volume of electrolyte displaced and hence on the volume of the particle. For an aggregate, the pulse height is proportional to the total volume of the constituent particles, without the included fluid.

The electrozone technique cannot conveniently be used over a very wide range of particle sizes. To detect particles reliably, an orifice is needed with a diameter not more than about 50 times the primary particle size. Particles smaller than about 0.5 μm are difficult to monitor, which is a serious limitation for colloids. Particles larger than about 40% of the orifice diameter also present difficulties because orifice blockage can become a serious problem. Thus, for a 50-μm orifice, particles in the size range of 1-20 μm could be measured. For a wider size range two or more orifice sizes have to be used, which is inconvenient.

Table 3 Advantages and disadvantages of microscopic technique and image analysis technique

Analysis techniques	Advantages	Disadvantages
Microscopic Analysis	•Microscopic evaluation allows you to "really" see the particles and evaluate their range of shapes and sizes. The method inspires great confidence in the results. a •A quick look with a microscope often gives a great deal of information that other methods are unable to give. •The microscope can be "calibrated" by looking at known size standards. (Weiner BB.)	•The number of particles measured is usually small compared to other particle sizing methods, so representative sampling becomes critical. •The method inspires too much confidence in some cases. It may be difficult to collect enough data to give a reliable result. A single 30 mm particle that is not counted represents the same weight of material as 27,000 particles of 1 mm that are counted. •Sample preparation for electron microscopes is slow, expensive, and requires considerable technical expertise. •For both an optical and electron microscopy, sample preparation is crucial. It is normally not possible to determine if two or more particles are just "touching" or if they are permanently stuck together; in other words, really just one bigger particle. This can lead to significant errors in reported size distribution.

Table 3 (cont'd) Advantages and disadvantages of microscopic technique and image analysis technique

Analysis techniques	Advantages	Disadvantages
Microscopic Analysis		•Anything more that a quick look with an optical microscope soon becomes very tedious. •Analysis time can be very long, especially for electron microscope analysis.
Image analysis	• Non-intrusive the system • Size range from micron up to several millimeters •Inexpensive •Make measurements at higher densities that were before not thought possible •Analyze many particles at once •Real-time analysis possible •Hardware and software are readily available •Can count particles and measure physical properties such as particle radius and area •Can measure distributions of particle properties	•Particle with shape edges are identified and separated from the background. •experienced by the digital camera •If the image are not well and sharp contrasted from the background, there is possibility of over-sizing due to fuzzy at the edges of the flocculent-floc.

Source: Eisma (1986), Gibb (1982), and Weiner, BB.

Image analysis in flocculation process

Image analysis is the extraction of useful information from images; mainly from digital images by means of digital image processing techniques. Image analysis tasks can be as simple as reading bar coded tags or as sophisticated as identifying people by their faces. Computers are indispensable for the analysis of large amounts of data, for tasks that require complex computation, for the extraction of quantitative information such as particle counts, areas, or integrated densities. On the other hand, the human visual cortex is an excellent image analysis apparatus, especially for higher-level information; and for many applications - such as medicine, security, biology, remote sensing - human analysts still cannot be replaced by computers. For this reason, many important image analysis tools - such as edge detectors and neural networks try to mimic human visual perception processes, or were at least inspired by them. Digital image analysis largely consists to the fields of computer and machine vision, and is strongly connected to pattern recognition and signal processing. The technique can make use of devices such as cameras, lasers, radar, sonar, seismographs or gravimeters. Modern remote sensing normally includes digital processes but can be done as well be done with non-digital methods.

Image analysis as a technique for the quantification of particle size and shape information has existed for many years. Prior to the advent of digital image analysis simple measures such as diameters were used to classify particle size, and simple ratios of such measures could be used to describe particle shape. Microscopic analysis is often difficult to measure accurately using existing technologies. It requires samples to be withdrawn and the particle to be passed through a small orifice, which may cause the floc to break apart and disperse (Gibb, 1982). Since the flocs break up easily during sampling and handing (Eisma, 1986). In-situ or optical techniques avoid these problems (Gibbs, 1982). Nature floc have been studied up to now only by direct observation in the water, by in-situ photography has yielded some information on size and shape of the floc but reliable size distributions have not yet been obtained, mainly because the technique of size analysis of floc in-situ have not yet given quantitatively reliable results for the whole size range (Eisma, 1986).

Manual microscopy is time consuming, expensive, tedious and prone to operator bias. The microscope-quality level of information combined with the statistical significance of traditional ensemble techniques allows the instrument to be used as a sensitive trouble-shooting tool–identifying the source of manufacturing problems much sooner than previously possible. Adverse effects due to inherent quality variability are often not recognized until after manufacture. Manual microscopy and traditional particle sizing techniques are often not sufficiently sensitive to distinguish subtle differences in raw materials. Shape parameters give you a level of particle characterization that is much more sensitive allowing you to make the correct decisions earlier in the manufacturing process so reducing costs and cycle times.

While the human eye and brain are highly sophisticated at image interpretation and pattern recognition, they are poor at objective quantification. Computer-based image analysis, therefore, has several advantages including; consistency; precision; speed of measurement; increased data-handling capacity; and cost-effective use of effort and expertise (Tyson, 1990). Image analysis requires conversion of an analogue image into digital (numerical) form, the operations performed and the subsequent measurements obtain from that digitized image. An image may be digitized by several methods, including a scanner, digital-camera or, as here, (microscope-mounted) video-camera.