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Wastewater Treatment Process by Physico-Chemical Methods

Dr. Bhoopendra Singh

Associate Professor, Department of Chemistry, Agra College, Agra, Uttar Pradesh, India

ABSTRACT

Contaminated water contains particles of different sizes which can be classified as dissolved (< 0.08 µm), colloidal (0.08 - 1 µm), supracolloidal (> 100 - 100 mm) and settleable (> 100 µm). The type of treatment selected depends on the size of particles present in the wastewater. In practice, treatment efficiency also depends on particle size. Solids of the size that are visible to the naked eye can be separated either by settling under the influence of gravity or by flotation, depending on the relative densities of solids and water. They may also be easily separated by filtration. However, very fine particles of a colloidal nature (called colloids, size < 1 µm) which have high stability are significant pollutants. The reason for this stability is that these particles have electrostatic surface charges of the same sign (usually negative). This means that repulsive forces are created between them, preventing their aggregation and subsequent settling. It has therefore proved impossible to separate them by settling or flotation. It is not possible to separate these solids by filtration because they pass through any filter. However, separation by physico-chemical treatments is possible. Physico-chemical treatment of wastewater focuses primarily on the separation of colloidal particles. This is achieved through the addition of chemicals (called coagulants and flocculants). These change the physical state of the colloids allowing them to remain in an indefinitely stable form and therefore form into particles or flocs with settling properties.

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INTRODUCTION

The physico-chemical process consists of coagulation, flocculation and sedimentation stages. However there may be configurations where all stages are carried out in the same unit

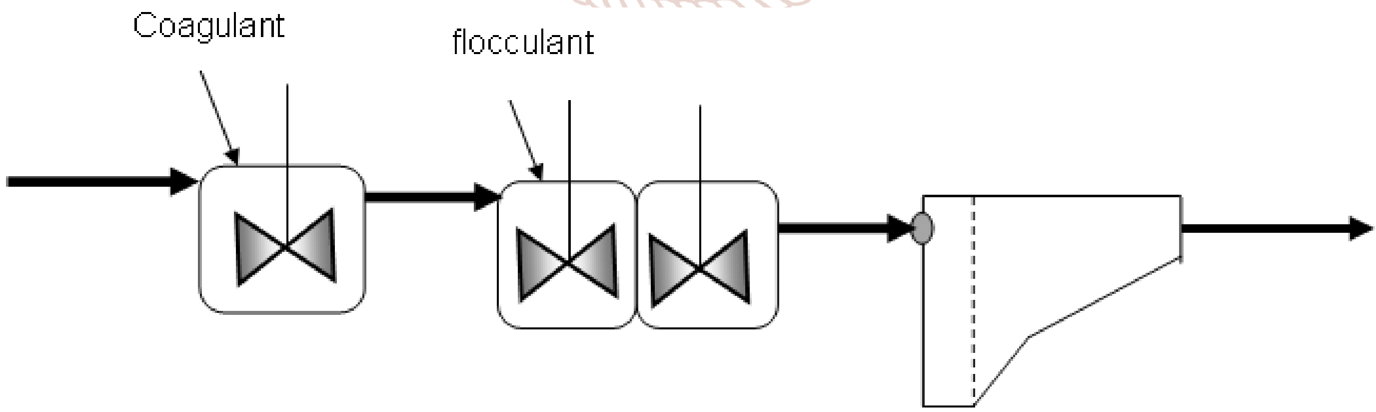

Figure 1 Components of conventional physico-chemical treatment

Coagulation (or rapid mixing)

Derived from the Latin coagulare meaning driving together, coagulation refers to destabilization or neutralization of the negative charges contained in the wastewater by the addition of a coagulant applied during rapid mixing (which can vary from 250 - 1500 s-1) and a very short contact time (times ranging between 5 - 60 s). The quantity of coagulant applied during coagulation depends on the quality of water (domestic or industrial). In the case of domestic water, commonly used doses are < 50 mg/L, while for industrial water the dose is very variable. The most commonly used coagulants are ferric chloride, ferric sulfate, aluminium sulfate, aluminium polychloride, sodium aluminate mixtures of organic and inorganic compounds, lime and the more recently studied application of iron polychloride.[1,2]

Flocculation (or slow mixing)

This is derived from Latin floculare, referring to the formation of flocs and bridges. In this stage, previously formed flocs group together, increasing in volume and density, allowing them to be sedimented. This is achieved by applying a gradient (10 to 100 s-1) and a contact time varying between 15 min and 3 h

- By the movement of particles themselves (Brownian motion). In this case flocculation is referred to as perikinetic or natural convection
- By the movement of the fluid containing the particles, inducing their movement. This is achieved by agitating the mixture. This mechanism is referred to as orthokinetic or forced convection flocculation[3,4]

During the flocculation stage, chemicals referred to as flocculants are applied (assisted flocculation). These products allow flocs to come together and adhere, increasing their size and density. Flocculants can be classified by their nature (mineral or organic), their origin (synthetic or natural) or their electric charge (anionic, cationic or non-ionic).

Organic flocculants of natural origin are derived from natural products such as alginates (seaweed extract), starches (plant grain extracts) and cellulose derivatives. Their effectiveness is relatively low.

Those of synthetic origin are long chain macromolecules, soluble in water, formed by the association of simple synthetic monomers, some of which have electric charges or ionisable groups. For these reasons they are referred to as polyelectrolytes. These products are highly efficient and recommended concentrations are 0.05% -0.1% for solid products, 0.1% - 0.2% for liquid dispersion and 0.5% - 1.0% for liquids in solution. Applied in excess they may harm the flocculation process[5,6]

Sedimentation

This is the stage of floc removal by solid - liquid separation. For this, low, medium and high rate settlers are commonly used. The rate is determined by the speed at which water and sludge are produced by the system.

Determination of Design and Operating Conditions Using "Jar Tests"

There are many aspects (physico-chemical properties of the wastewater of interest) that affect the performance of physico-chemical treatment. These can be determined by traditional laboratory jar tests or by RoboJar systems .The system consists of six jars of the same size to which varying doses of coagulant are added at the same time. The system implements a rapid mixing sequence for a predetermined time followed by slow mixing for a set time and finally a settling sequence. After this, the supernatant is drained. Jar tests give a good approximation of the actual treatment process and the rapid mixing, slow mixing and sedimentation conditions of a real plant. At the beginning, middle and end of the treatment tests, it is necessary to evaluate the efficiency of the process. This is achieved by measuring traditional parameters such as TSS, COD, pH, conductivity, turbidity, alkalinity, BOD, nutrients (N and P), thus establishing the efficiency of the system. Other parameters of greater accuracy such as particle size distribution, zeta potential and/or electrophoretic mobility may also be used.[7,8]

Physico-chemical treatment may constitute a single stage in the wastewater treatment process or be added as an additional treatment process during pre-treatment (to improve the biodegradation of wastewater in the biological process and secondary treatment (such as polishing).

Physico-chemical processes have been implemented for over 100 years. However in 1930, these processes were replaced by biological processes due to the high costs incurred by the treatment of large quantities of sludge. Recently, they have been reintroduced for various purposes: the elimination of phosphorus. for effluent being discharged to the sea, obtaining average quality effluent at lower cost than conventional treatments and for water used for agricultural irrigation, for potabilization. industrial water treatment, conditioning of sludge (primary and/or secondary) ,The resurgence of these processes is also due to increased recognition that the cost of treatment should be consistent with the desired efficiency, as progress in the synthesis of flocculation polymers with high efficiencies has been achieved at a lower cost .

Using this type of process it is feasible to remove 80 to 90% of total suspended solids (TSS), 40 to 70% of BOD5, 30 to 40% of COD and 17 to 100% of nutrients (N and P), depending on the dose and type of coagulant used .Heavy metals may also be removed by these processes, but the removal efficiency depends on the metal type and concentration. Recently, these processes have been used to remove pathogens such as helminth eggs and have proven to be capable of removing up to 2 log concentration. In addition they are very efficient when used to remove bacteria (0-1 log unit), viruses and protozoa (1-3 log units in each case). Current studies are focusing on their use for the removal of emerging contaminants .[9,10]

Discussion

In detailed forms of physical and chemical treatment of wastewater:-

Depending on the composition of the wastewater, the chemical and physical treatments often take place in individual steps. DAS Environmental Expert effectively combines these process steps with the right wastewater technology as an efficient and cost-effective solution for the treatment of the client's wastewater.

After selecting the ideal combination of procedures, our experts in project management will accompany you during the planning and construction of your plant.

Wastewaters containing water insoluble substances or colloids are effectively treated through processes such as sedimentation, filtration and centrifugal separation. Flotation, where substance particles stick to fine air bubbles due to adhesive forces is another process that, depending on the wastewater's composition, Environmental Expert often uses as part of the physical treatment stage. Reliable, mechanical preliminary cleaning is particularly important for the treatment of sanitary wastewaters in order to prevent damage in the subsequent treatment stages. [10,11]

Chemical wastewater treatment forces contaminants that are dissolved in wastewater to separate more easily through the targeted addition of specific substances. During precipitation, a previously dissolved substance is turned into a dissoluble substance that can be filtered from the liquid. Other methods of pollutant removal are ion exchange, flocculation, UV and ozone treatments.

Physical Wastewater Treatment Processes

Coarse-and-Fine Materials Separation Utilizing Screens and Strainer

Screens and strainer remove solid contaminants from wastewater. These mechanical processes separate solid pollutants such as diapers, hair, and wet wipes from the wastewater stream. Before the treatment of industrial wastewaters, strainer separate textile fibers, paper labels, plastic residuals, and production residues such as potato peels and other scraps and wastes.

Depending on the area of application, coarse or fine screens are used. They clean the wastewater by means of parallel rods. Strainer feature grits, screens, perforations and meshes of varying sizes. Coarse strainer (> 20 mm) to micro (<0.05 mm) separate solid substances as large as human waste to as small as sand and tiny sludge particles from the wastewater stream.

Extremely important is the mechanical preliminary cleaning in the treatment of sanitary wastewaters. Fibers suspended in the wastewater pose a particular challenge, especially the extremely tear-resistant textile fibers of wet wipes and non-woven materials. They tend to build up, potentially creating blockages and enormous damage to pumps and mixers. [12,13]

Mechanical Separation of Solid Substances through Filtration

Filtration separates solid substances from fluids. To this end, the mixture passes through a filter made of paper; whereas, technical applications typically utilize filters made from textiles or metal. Sand filters, cloth filters and drum screens are also frequently used as filtration systems.

Filtration systems remove organic and inorganic suspended solids, sands and dusts from wastewater. Wastewater technology employs this mechanical separation process to drain sludge in filter presses, among other processes. Filtration, typically in multistage processes, is also used for the purification of surface water to provide domestic and potable water.

Membrane filtration is another mechanical separation process in which a membrane functions as the filter medium. This method is typically used to separate very fine particles.[14,15]

Membrane filtration separates and concentrates dissolved and un-dissolved substances from wastewater. This separation is performed under pressure. Due to its specific pore size, the membrane retains particles and molecules of a certain size. Different methods of membrane filtration are used for water purification, wastewater treatment, process water recycling, and the collection of recyclables in the recovery of valuable substances.

Microfiltration is employed to separate particles, bacteria and yeasts. It is also used for cold sterilization and for the separation of oil-water emulsions.

Ultrafiltration is an important method for the treatment of wastewater and potable water. It serves to separate particles, microorganisms, proteins and turbidities from the water. Ultrafiltration is used in the Membrane Activation Reactor (MBR).

For instance, ultrafiltration is used to clean water in swimming pools. Since the build-up of clogging deposits on the membrane can be prevented, more and more pre-existing wastewater treatment systems are being complemented with ultrafiltration as a final step. When retrofitting older wastewater treatment plants, the ultrafiltration step can be positioned directly inside or as a separate stage after the activation tank in order to replace subsequent treatment steps or to increase the treatment capacity of the biological wastewater treatment.

Nanofiltration retains viruses, heavy metal ions, large molecules and very fine particles. The method is used for water softening and the treatment of potable water.

Reverse Osmosis is an important process to concentrate landfill wastewaters, treat potable water in rural areas that are not connected to a pipeline network, desalinate seawater and decalcify boiler water in power plants. This method concentrates substances that are dissolved in fluids by applying pressure through a semi-permeable membrane that reverses the process of osmosis. When the applied pressure is higher than the respective osmotic pressure, the molecules of the solvent diffuse to the side of the membrane where the dissolved substance is already less concentrated. Reverse osmosis is also used to produce ultrapure water.

Wastewater Treatment through Flotation
Flotation removes dispersed or suspended substances from fluids by means of very fine gas bubbles that transport the substances to the surface, and subsequently, bubbles and substances are removed with a clearing device. In wastewater treatment, the flotation processes are used to separate oils, fats and finely suspended solids and particles.

Solids Separation through Sedimentation
Sedimentation uses gravity to separate solid particles in sedimentation tanks. A sedimentation tank is a flat, nearly current-free tank specifically designed for sedimentation processes. The solid particles settle on the bottom of the tank.[16,17]

Wastewater treatment uses sedimentation processes in various ways. In the preliminary cleaning tank, un-dissolved substances settle and form primary sludge that is subsequently concentrated in the digestion tower where it is transformed anaerobically. The transformation process produces digested sludge and fermentation gas, which, in its cleaned form like biogas, is converted into electricity to cover energy demands. Aerobically produced sludge is also added to the digestion tower after it has been separated from the wastewater through sedimentation in the clarifier tank. In addition, sand traps and sludge collectors separate particles that are heavier than water.

Wastewater Treatment through Chemical Processes

Neutralization
Wastewater technology uses neutralization to adjust the pH value. Acids or alkali are added, as required, after processes like precipitation and flocculation, and for the neutralization of industrial wastewaters.

Oxidation/Reduction
Redox reactions are frequently utilized in chemical wastewater treatment and in the treatment of potable water. Oxidation processes with ozone and hydrogen peroxide efficiently remove chlorinated hydrocarbons and pesticides from potable water.

In wastewater treatment, oxidation processes are used to remove difficult biodegradable compounds. Particularly efficient is photochemical purification, which forms hydroxyl radicals from hydrogen peroxide or ozone through UV-light exposure. These Advanced Oxidation Processes (AOP) are used to degrade drug substances like antibiotics, cytostatic drugs, hormones and other anthropogenic trace substances.

In addition, ozone aids in the oxidization of iron and manganese in well water. Reduction processes are required to transform heavy metal ions, for instance, into easily dissoluble sulfides.[18,19]

Adsorption and Chemisorption
Adsorption is the accumulation of substances on the surface of a solid body, which is a physical process where molecules stick to boundary surfaces through the van der Waal force. If chemical bonding binds substances to the surface of a solid body, the process is called chemisorption. In contrast to adsorption, chemisorption is non-reversible.

Wastewater treatment uses activated carbons to bind soluble water contents that could not be sufficiently removed with lower-priced methods such as biological wastewater treatment, precipitation and flocculation. Colorants from textile dying plants, for instance, often can only be completely removed through adsorption on activated carbon. Anthropogenic trace elements such as pharmaceutical residues and polar organic substances like adsorbable, organically-bound halogens (AOX) also bind to activated carbon.

Doped activated carbon can also be employed to remove arsenic and heavy metals. Granulated iron hydroxide is another ideal agent to remove toxic metalloid arsenic from potable water, contaminated ground water and industrial wastewaters. In this process, the iron hydroxide reacts with the arsenate ions to form iron arsenate. This method is efficient as well as cost-effective.

Precipitation
Precipitation is a chemical process that separates a previously soluble substance from a fluid. A common method is to create a precipitation reaction by adding

suitable agents. Through precipitation, heavy metals, for instance, transform to not easily soluble metal hydroxides. Other situations may require precipitation to carbonates or sulfides.

Anions can often be precipitated as calcium, iron, and aluminum salts. The separation of fluoride ions, for instance, is achieved through precipitation with milk of lime. During wastewater treatment in the treatment plant, adding salts like iron(II) sulfate, iron chloride or aluminum chloride lowers the phosphate concentration. The phosphate precipitation can either be integrated as simultaneous precipitation into the biological treatment stage or added as a subsequent separate process step. [20,21]

Flocculation

Flocculation prepares very fine particles that are present either suspended or in the form of colloidal solutions, for removal from water. If the surface charge of this very fine particulate matter is the same, the particles cannot, due to mutual electrical repulsion, accumulate to larger **agglomerates.**

In this case, suitable chemicals, flocculants and flocculation aids help achieve the agglomeration of such particulate matter, creating macro flakes that sediment. Flocculation is used to improve settling properties as well as to drain sewage sludge. Employing iron and aluminum salts for flocculation allows the flocculating of phosphate at the same time.

Ion Exchanger

Ion exchangers are materials that can replace the ions of one solution with other ions. The cation exchanger, for instance, replaces calcium ions with sodium ions. Once the ion exchange is exhausted and the calcium ions are completely saturated, the ion exchanger needs regeneration.

This success of this process is based on the principle of displacement: the higher the ions' charge, the stronger the ion-binding to the ion exchanger. If both types of ions are charged the same, the one with the larger radius will be the one with the stronger ion-binding force. During the ion exchange process, the stronger-binding ion will displace the lesser-binding ion.

Ion exchangers are suitable for the removal of heavy metals and anions and are therefore often used as 'policing filters' after precipitation and flocculation. In addition, they assist with water softening, changing the water's salt content, and water desalination; particularly important for the semiconductor industry that uses them to produce extremely clean, demineralized water known as ultra-pure water.[21]

Results

Wastewater Treatment Plants as a Point of Control

WWTPs are a significant point source for antimicrobials. WWTPs are relatively nutrient-rich, heavily contaminated environments that receive waste from a variety of particle-loaded environments, including hospitals, industrial and agricultural sites and release both solid and liquid by-products that can disseminate particles. Influent can be contaminated with a variety of pollutants, including antimicrobial agents, pharmaceuticals, personal care products, and heavy metals, which can accumulate within WWTPs. Many microbial and chemical contaminants in wastewater cannot be degraded by the treatment process or inactivated through disinfection of the effluent. For those contaminants that can be degraded, the resulting metabolites may still have antimicrobial or selective activity. WWTP effluent and solid waste products not only have a high prevalence of particles but also release selective agents into the receiving environments

The nature of biological treatment can also encourage the dissemination of AMRD into the environment and within the wastewater microbiome. Microorganisms are found in a variety of states in WWTP including in planktonic form, flocs suspended in the wastewater, and biofilms attached to solid surfaces .The presence of microorganisms in flocs and in biofilms may be significant in establishing the basis of why WWTPs are considered both hot spots for gene transfer and possible reservoirs for Antimicrobials.

Microbial community composition in a WWTP affected coliforms. Additionally, different WWTPs have different efficiencies for the removal of microbes. Both operational conditions and design can influence the fate of microbial removal in WWTPs. There have been numerous studies to determine which treatment systems and operational conditions impact antimicrobials. For instance, it was found that both organic loading and growth rate resulted in the amplification of tetracycline resistance in WWTPs using biological treatment processes. Researcher used metagenomic approaches to compare the fate of microbial in anaerobic, aerobic, and anaerobic-aerobic sequence bioreactors (AASs). AASs and aerobic reactors were superior to anaerobic reactors in reducing microbial abundance, particularly aminoglycoside, tetracycline, and beta-lactam determinants. Sulfonamide and chloramphenicol anti-microbial levels were unaffected by treatment, and a shift from target-specific Antimicrobials associated with multidrug resistance was seen in influents and effluents from all WWTP. The AASs used 32% less energy than aerobic reactors and favorably reduced Antimicrobials abundance. The chemical properties of the wastewater, including chemical oxygen demand (COD), ammonia (NH_3–N), suspended solids (SS), dissolved oxygen, and temperature, can impact the fate of different antimicrobials. For instance, it is found that the COD was highly correlated with the fate of tetW, intI1, and sul1. It has been indicated that most antimicrobials were positively related to COD and SS of raw sewage and negatively correlated to the corresponding variables in the effluent.[22]

Similarly, the choice of disinfection method can impact the fate of antimicrobials in WWTPs. Disinfection may not reduce the abundance of antimicrobials in the effluent as it was observed when studying the presence of tetracycline and sulfonamide and their resistance determinants within five WWTPs in Michigan. The use of chlorination and UV radiation for disinfection is common, and the effectiveness of these strategies for removing antimicrobials varies as a result of multiple factors. For instance, it was compared the inactivation of antimicrobials in municipal wastewater effluent by chlorination, UV radiation, and sequential UV/chlorination. They found that chlorination was more effective than UV radiation in removing antimicrobials from WWTP effluent and that its efficiency was affected by NH_3–N concentration. The presence of high NH_3–N in wastewater corresponds to a decline in antimicrobials removal .Free chlorine was also more effective than combined chlorine, and a combination treatment of UV irradiation followed by chlorination showed higher antimicrobials removal efficiency than UV or chlorination alone.

The methods of evaluation of antimicrobials in WWTPs can make the comparison of studies difficult. In some studies, a culture-dependent step is crucial and the focus is mainly on the detection and fate of antimicrobials, whereas others use a combination of culture-dependent and -independent techniques and have shifted the focus to MGE, Studies that use a combination of culture-dependent and -independent techniques provide more comprehensive information than studies that use only one technique or the other. Culture-dependent studies provide valuable information about the expression of antimicrobials but neglect the impact of extracellular and unexpressed antimicrobials ,whereas culture-independent methods may not account for the function of those genes.

The complexity of the engineered system can obscure the influence of antimicrobials on the spread and prevalence of antimicrobials both within the WWTP and in their effluent. This can make elucidating the factors and mechanisms responsible for the increased prevalence of antimicrobials more difficult and determining their relative importance is a constantly evolving area of research. The high degree of gene transfer that can occur in WWTPs and the high prevalence of antimicrobials in microorganisms isolated from wastewater would suggest that WWTPs are a point source for antimicrobials -related environmental contamination. An engineered system, like a WWTP, may be ideal for environmental public health monitoring, and surveillance efforts and management strategies could be developed that are targeted at reducing the release of antimicrobials into water and soil environments.[23]

References

[1] Levine A, Tchobanoglous G. and Asano T. (1991). Size distribution of particulate contaminants in wastewater and their impact on treatability, Wat. Res., 25(8): 911-922.

[2] van Nieuwenhuijzen A. F, van der Graaf J., Kampschreur M. and Mels A. (2004). Particle related fractionation and characterisation of municipal wastewater, Wat Sci. and Tech., 50(12): 125–132.

[3] O´Melia Ch., Hahn M. and Chen Ch. (1997). Some effects of particle size in separation processes involving colloids, Wat Sci. Tech., 36 (4): 119-126.

[4] Menezes F. M., Areal R. and Luketina D. (1996) Removal of particles using coagulation and flocculation in a dynamic Separator, Powder Technology, (88): 27-31.

[5] Tambo N. and Watanabe Y. (1984). Physical aspect of flocculation process –III. Flocculation process in a continuous flow flocculation with back-mix floc, Wat. Res., 8(6): 695-707.

[6] Rzbhun M, Fuhrer Z. and Adin A. (1984). Contact flocculation – filtration of humic substances. Wat. Res. 18(8): 963-970.

[7] Amuda O. S and Alade A. (2006). Coagulation/flocculation process in the treatment of abattoir wastewater, Desalination, (196), 22–31.

[8] Rossini M., Garcia G., and Galluzo M. (1999). Optimization of the coagulation –flocculation treatment: influence of rapid mix parameters, Wat. Res. . 33(8): 1817-1826.

[9] Jiménez, B. and Chávez, A. (1997). Treatment of Mexico City Wastewater for Irrigation Purposes, Environmental Technology, 18(7): 721-729.

[10] Bolto B. Gregory J. (2007) Organic polyelectrolytes in water treatment, Water Research, (41): 2301 – 2324.

[11] Rattanakawin Ch. (2005). Aggregate size distributions in sweep flocculation. J. Sci. Technol., 27(5): 1095-1101.

[12] Mhaisalkar V. A., Paramasivam R. and Bhole (1991). Optimizing physical parameters of rapid mix design for coagulation-flocculation of turbid water. War. Res. 25 (I): 43-52.

[13] Chavez A., Jimenez B. and Maya C. (2004). Particle size distribution as a useful tool for microbialdetection Wat. Sci. and Tech., 50 (2): 179-186.

[14] Kim S., Kim H., Moon B., Seo G. and Yoon C. (2006). Effects of addition sequence and rapid mixing conditions on use of dual coagulants. Wat. Sci. & Tech., 53(7): 87–94.

[15] Lawler D. (1997). Particle size distribution in treatment processes: Theory and practice. Wat. Sci. Tech., 36(4): 15-23.

[16] Duan J and Gregory J. (2003). Coagulation by hydrolyzing metal salts. Advances in Colloid and Interface Science, (100 –102): 475–502.

[17] Odegaard H. (1998). Optimised particle separation in the primary step of wastewater treatment. Wat. Sci. Tech., 37(10): 43-53

[18] Suarez S, Lema J., Omil F. (2009). Pre-treatment of hospital wastewater by coagulation–flocculation and flotation. Bioresource Technology, (100): 2138–2146.

[19] Park S, Jun H, Jung M and Koo H (2006) Effects of velocity gradient and mixing time on particle growth in a rapid mixing tank. Wat. Sci. & Tech., 53 (7): 95–102.

[20] Jimenez, B. and Chavez, A. (1998). Removal of Helminth eggs in an advanced primary Treatment with sludge blanket, Env. Tech., 19 (11): 1061 – 1071.

[21] Shao Y. Lui A., Wada F., Crosse J. and Jenkins D. (1996). Advanced primary treatment: An alternative to biological secondary treatment. The City of Los Angeles Hyperion treatment plant experience., Wat. Sci. Tech. 34 (3-4): 223-233.

[22] Haarhoff J. and Joubert H. (1997). Determination of aggregates and breakup constants during flocculation. Wat. Sci. Tech. 35(4): 33-40.

[23] Amuda O. Amoo I. (2007). Coagulation/flocculation process and sludge conditioning in beverage industrial wastewater treatment, Journal and hazardous Materials, (141): 778-783.