Effluent Treatment by Activated Sludge Process

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"Activated Sludge treatment has become increasingly popular for treating pulp and paper industry waste waters in Finland, Canada, European countries and Asian countries. The common problems in ASP are too high floc load due to bulking sludge, inadequate Nutrient addition, Lack of Oxygen, pH increase in aeration, Fatty and resin acids, Toxins & lack of essential metals such as Iron, etc. The factors affecting the ASP efficiency are Variability in waste water flow and quality, Sludge retention time, Hydraulic retention time, Organic loading (F/M ratio), Macronutrient levels, Mixed liquor suspended solids (MLSS) concentration, Mixing and aeration intensity and Mixed liquor oxygen level, Mixed liquor temperature, Mixed liquor pH value. Most of the companies worldwide are shifting towards ECF, TCF bleaching technology by eliminating chlorine, chlorine dioxide and hypo chlorite and also in paper making from acid sizing to alkaline sizing. Worldwide survey of ASPs is indicating the Bulking Problem more in ECF &TCF bleaching than the Chlorine and Hypo conventional bleaching. As JKPM moving towards ECF bleaching, alkaline sizing paper technology, low water consumption in process and close looping of the system, high concentration of pollutant with high temperature effluent is generated. Hence, JKPM modified the existing effluent treatment system with a New Activated Sludge Process with cooling Tower. Due to the effective control of ETP process parameters by Operators, JKPM achieved the best result of BOD, COD, SS and pH of out going discharge treated effluent on a continuous basis.

INTRODUCTION

The main pollutants in the effluent are JK Paper Mills, Oxygen Demanding Substances- BOD, COD, TOC, TOD, Disease Causing Agents, Synthetic Organic Compounds - Detergents, Pesticides, Oil and grease, industrial chemicals, Poly chlorinated biphenyl compounds, Chloroform, Dioxin, Adsorbable Organic Halide, Color, Endocrine disruptors, plant nutrients- Low in Nitrogen and phosphorous, Inorganic Chemicals and Minerals Substances- acid, alkalis, heavy metals, Sediments- Total solids, Dissolved solids, suspended solid, Thermal Discharges- Effluent with high temperature and Radio Active Materials - Rare use in pulp and paper industry. They contribute to BOD, COD, suspended solids, pH variation in the effluent and it needs treatment before its disposal.[1]

There are various biological treatment systems like oxidation pond, trickling filters, aerated lagoons and activated sludge process, where the tiny micro-organisms are utilized to bio-degrade (synthesis) the carbonaceous organic materials (dissolved / undissolved) present in the effluent. In the aerobic treatment process the oxygen supplied is utilized by the microorganism to oxidize organics to carbon dioxide, water and metabolic energy, whereas in the anaerobic treatment process, the organics are reduced to methane, carbon dioxide and water. The anaerobic system is generally preferred where the BOD level is higher than 2000 mg/ltr or else aerobic system is employed. At JKPM, the incoming BOD varies from 250 / 350 mg/ltr and thus the plant has been augmented by adding activated sludge process with cooling tower in addition to aerated lagoon (utilized as shock load).

Treatment Process At JKPM (Fig. 1)

The treatment process involves the following three major steps

- Removal of settleable solids from combined effluent.
- Bio-degradation at activated sludge basin (ASB).
- Sedimentation to recover and maintain healthy micro-organism at ASB.

Removing Settleable Solids

The waste water (effluent) from various sections of the mill is brought to ET Plant through channels to a collecting pit. A number of bar screens have been installed in the channel to trap and remove the coarse suspended solids like leaf, plastic pieces and uncooked bamboo pieces etc. The pH of the effluent (contributed by contaminants like acid & alkali) is controlled between 6.5 to 8.5 by dosing Hydrochloric acid / Calcium hypochlorite solution as required. The effluent is pumped to primary clarifier through grits chambers and further settleable fine solids like uncooked fibres, pulp, grits, lime sludge, talcum powder etc. are removed to the tune of 90 - 95%. The recovered organics and inorganics from the underflow of clarifier is screened through vibro-screens and dewatered through twine wire presses and the cake (having 35 to 40% solids & balance water) is sold to outside agency for making pulp board.

Biodegradation

The effluent from primary clarifier overflow containing dissolved organics / inorganics [which result into Bio-chemical Oxygen Demand (BOD) & Chemical Oxygen Demand (COD)] and unsettled fine Suspended Solids (SS) is then subjected to biodegradation process. The overflow of primary clarifier effluent at 38/48°C temperature goes to a cooling tower and where by the temperature maintained at AS Basin is 34 - 37°C. At inlet launder of Activated Sludge Basin (ASB), the cooled effluent is mixed-up with calculated dose of nutrients like Urea and DAP (Diammonium phosphate). The activated sludge basin volume has been designed for a effluent flow rate of 40000 M^3/day with BOD reduction by 90% (i.e. from 200 ppm to 20 ppm) with MLSS of 2700-3000 mg/ltr, and F/M ratio of 0.25. The 8 nos. 50 HP, slow speed aerators supply required oxygen to micro-organism. The process of conversion of dissolved organics / inorganics materials to bacteria and reduction of BOD & COD to the tune of 90% and further reduction of bacteria to gases and waste product takes place at ASB. The following chemical reactions take place at ASB(Table) : -

Thus the activated sludge process is a complex oxidizing process where the micro-organisms are grown and population is maintained to synthesize the dissolved / undissolved carbonaceous organic / inorganic materials present in the effluent to biological cell and the end products. (2)

Sedimentation to recover micro-organism

The cell tissues generated during biodegration have specific gravity slightly more than water and thus they can be removed from the treated effluent by gravity settling. So after the above reaction, total mixed liquor with suspended solids is taken to secondary clarifier, where the micro-organism and sludge are settled. As per experience, the new growth of cell tissue is equivalent to about 32% of BOD input hence 32 % is wasted to balance desired concentration of organism at ASB. About 68% of the underflow settled sludge is recirculated to balance the population of micro-organism in the Activated Sludge Basin. The excess sludge of secondary clarifier is discarded to drying bed, whereas the clear treated effluent overflowing the clarifier is discharged to River Nagavali and land Irrigation.

Design & Control parameters of Activated Sludge Process

To design and operate activated sludge process system efficiently, it is utmost important to understand the importance of the micro-organism in the system. Microbial waste water treatment involves consumption of impurities as food by the active micro-organism, generation & growth of micro-organisms in the process. The micro-organisms in Activated Sludge Basin are bacteria, fungi, algae, protozoa, rotifiers and viruses etc.

Table 1 : Aerobic chemical reactions at ASB

1. Oxidation Process:

$$\underset{\text{(Organic matter)}}{COHNS} + O_2 + \text{Bacteria} \rightarrow CO_2 + NH_3 + \text{Energy} + \text{End products} \quad ......(1)$$

2. Synthesis Process :

$$\underset{\text{(Organic matter)}}{COHNS} + O_2 + \text{Bacteria} + \text{Energy} \xrightarrow{\text{pH 6.5 to 7.5}} \underset{\text{(New bacterial cells)}}{C_5H_7NO_2} \quad ....(2)$$

3. Auto Oxidation Process (Endogenous respiration):

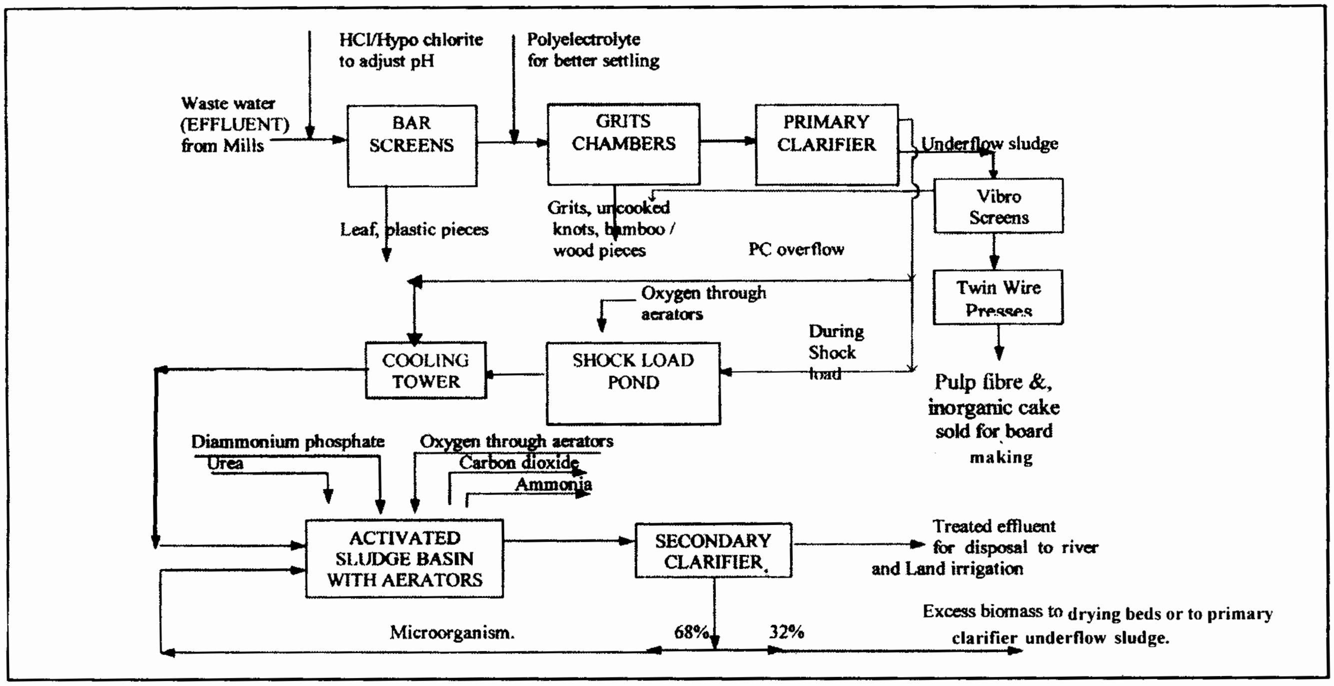
$$\underset{\text{(Cell tissue)}}{C_5H_7NO_2} + 5O_2 \rightarrow 5\,CO_2 + 2H_2O + NH_3 + \text{Energy} \quad ......(3)$$

4. Formatting of Algae:

$$CO_2 + 2H_2O \xrightarrow[\text{in presence of inorganic compounds, nitrogen \& phosphorous}]{\text{Photosynthesis through sunlight}} \underset{\text{New Algae Cells (produce bad taste \& odor)}}{CH_2O} + O_2 + H_2O \quad ....(4)$$

$$\underset{\text{New algae Cells}}{CH_2O} + O_2 \xrightarrow{\text{at night}} CO_2 + H_2O \quad .... \; .... \; .... (5)$$

Fig . 1 : Effluent treatment process at JKPM.



One protozoa (single cell, longer in size than bacteria) consumes thousands of dispersed bacteria (which have not flocculated) and produces improved quality settleable biological floc and thus act as polisher. The rotifiers (multicellular animal) consume dispersed and flocculated bacteria and organic particles (which do not settle) and improve the treatment efficiency. Hence, the population of both protozoa and rotifiers indicate the maturity of system. Their population is maintained carefully at an optimum level by avoiding shock loads of pH, Temp & BOD and adding proper nutrients or by substituting for dead micro-organisms through external dosing. To ensure good settling characteristics, the microbial growth in the mixed liquor is maintained in the declining growth phase.

Table 2: Bacterial Composition

Approx. composition of 20-25% dry mass :

Carbon	–	50%
Oxygen	–	20%
Nitrogen	–	14%
Hydrogen	–	8%
Phosphorous	–	3%

Balance 5% constitutes sodium, sulphur, potassium, magnesium & calcium etc.

The bacteria generally fall into following three categories:

1. Spherical (0.5 to 1.0 micron diameter)

2. Cylindrical (0.5 to 1.0 micron width x 1.5 to 3.0 micron length)

3. Helical (0.5 to 5.0 micron width x 6 to 15 micron length)

The bacteria grow from the constituents of effluent through binary fission and their life cycle varies from 20/30 min to 1 day. The composition of bacteria (Table-2) shows that it contains about 75 to 80% water. Out of 20 - 25% dry mass, about 90% mass include carbon, oxygen, nitrogen, hydrogen and balance as phosphorous, sodium, sulphur, potassium, magnesium and calcium etc. Hence, presence of these constituents in the effluent itself help to form new bacteria cell in presence of oxygen and energy released during oxidation of organics by the bacteria. So initial seeding of bacteria help in speeding up the growth. By photo-synthesis, in presence of nitrogen & phosphorous and sunlight, the algae is also produced which consume

Table 3: Design of Cooling Tower

Type	:	Induced Draft, Cross Flow.
Designed flow	:	1600 M^3/Hr
Designed temp. gradient	:	From 50° temp. gradientto 34°C
Effluent feed pump Duel speed	:	90 KW
Cooling Fans (2 nos.)	:	30 KW

oxygen at night and release carbon-dioxide. Thus, the complex Biodegradation process continues till suitable environment is maintained for their growth.[3 4]

Maintaining Healthy Bacterial growth

Growth of the micro-organism is delicately dependent on many factors such as incoming BOD feed rate, pH, temperature, dissolved oxygen in ASB, addition of nutrients like Urea and DAP, retention time at ASB proper mixing of recirculated bacteria with incoming effluent and the nutrients at feed launder, and desludging of dead bacteria from the system. These are very well controlled as detailed below :-

i) Control of temperature at ASB

Typically, most biological waste water systems in the pulp and paper industry are operated between 30 to 37°C. However, seasonal changes, the batch operation of upstream units, and overall process shut downs in the mill cause significant temperature variation in ETP. Input temperature to ETP varies from 37 to 48°C at JKPM due to high temperature at CDEopD bleaching stage. Such temerature fluctuations are suspected to cause poor solids separation in the secondary clarifier and high effluent suspended solid (ESS) level. Based on optimum temperature for growth of bacteria, these are classified as psychrophilic (temp from 4 to 10°C), mesophilic (temp from 20 to 40°C) and thermophilic (temp from 50 to 55°C). At low temperature the growth process slows down but as the temperature increases from 5 to 35°C, the rate of biological activity gets doubled for every 10 to 15°C. temp rise. The mesophilic bacteria grow efficiently at temperature between 20°C to 40°C, at constant BOD load, adequate nutrient dosing and pH between 6.5 to 8.5. It is critical to maintain the temperature variation within ± 0.5°C at ASB at all times on a consistent basis without a cooling tower (Table-3). The temperature at ASB is controlled by controlling outlet temperature from cooling tower by varying the speed of cooling tower fans.

ii) Control of pH

Most organisms cannot tolerate pH below 4.0. The filamentous fungi (multicellular protists) grow at pH less then 6.5, deficiency of nitrogen dosing, low dissolved oxygen and excessive sludge sugar. These fungi are lighter than water and floats in the effluent. So the secondary clarifier overflow becomes turbid and increases BOD of treated effluent. If the pH is more than 9, the microbial activity is inhibited. Bacteria's grow optimally at pH just above 7 whereas the Algae and fungi grow on acid side of neutrality. Sudden fluctuation of pH due to acid / caustic spillage to effluent, result into shock load and consequent death of many micro-organisms, which indirectly affect the BOD reduction efficiency of the system. Hence, pH of the incoming effluent to primary clarifier is controlled by addition of HCl or calcium hypo-chlorite depending on alkalinity and acidity of incoming effluent to maintain pH between 6.5 to 8.5.

Table 4: Nutrient Dosing

Length x breadth x liquor depth	:	82 M x 41 M x 4.5 M
Avg. BOD load	:	5040 Kg/day
Urea used	:	450 Kg/day
DAP used	:	210 Kg/day

iii) Control of Dissolved Oxygen (D.O)

The dissolved oxygen concentration for activated sludge process range from 0.2 to 2.0 mg/litre depending upon the characteristic of waste water and the type of activated sludge process. The micro-organisms need oxygen for their survival and reproduction. Since they cannot directly extract oxygen from the atmosphere either oxygen is dispersed through diffuser or through aerators. At JKPM eight nos. of slow speed 50 HPsurface aerators have been installed to supply 300 to 400 kg oxygen/Hr for supporting microbial growth depending upon effluent processing rate.

As the submergence increases due to increased flow, the oxygen transfer rate and load on to aerator also increases. The aerators submergence have been carefully set for a flow variation between 900 to1200 M^3/Hr so that aerator does not get overloaded when flow varies(5).

iv) Addition of nutrients

The nutrients dosing varies based on incoming BOD_3 in the ratio of BOD_3 : Nitrogen : Phosphorous from 100 : 6 : 1 to 100 : 3 : 0.6. Excess nutrient dosing may result into algae growth and bubbling at sec. clarifier, which affect the clarity of treated effluent.

Hence, for better growth of bacteria, calculated amount of Urea and DAP dosing in the ratio of BOD : Urea : DAP as 100 : 5 : 1 is carried out at the ASB launder through the dosing pumps (Table-4).

v) Toxicants

Toxic materials like sulphide, chloro-organics and metals like lead, copper, nickel and zinc may cause toxicity and destroy bacteria (6). Hence, tests need to be carried out in case the bacterial development is getting affected.

Once proper environment for micro-organism growth has been established, it is utmost important to ensure effective waste stabilization by controlling the desludging and controlling the growth rate of micro-organism.

Food/Mirco-organism ratio

The BOD_3 food (F) to micro-organism (M) ratio (F/M) is a very vital control parameter for Activated Sludge Process. When the F/M ratio is brought down below 0.8, initially the bacteria growth increases and then it

Table 5 : Operator check list

- Input pH to ETP needs to be checked and controlled ranging from 6.5 - 8.5.
- Colour is to be monitored visually at Inlet ETP.
- Sludge of Primary Clarifier is to be removed regularly. No jamming in Primary Clarifier.
- Inlet Temperature is to be recorded and communication to ASB and Cooling Tower people.
- pH and Temperature of P.C. Overflow is to be checked and cooling tower will be operated accordingly.
- Temperature, pH, BOD, COD, SS of PC Overflow is to be monitored.
- Activated Sludge Basin Mixed Liquor Suspended Solid, pH, Temperature, Dissolve oxygen, settling, SVI, MLVSS needs to be monitored.
- Urea & DAP dosing is to be checked.
- Aerator ampere load is to be controlled for better oxygen transfer.
- Secondary Clarifier underflow circulation rate to be monitered.
- Secondary Clarifier underflow consistency and its flow to ASB.
- pH, DO, BOD, COD, Temp, SS of Secondary Clarifier overflow.
- Turbidity and Clarity of Secondary Clarifier Overflow.

declines (due to oxidation) and sludge settling rate becomes faster (due to flocculation). When the F/M ratio is higher, the microorganism will have dispersed growth and the unused food will be carried to secondary clarifier. As a result, the treated effluent will become turbid and BOD_3 of treated effluent will be high. To overcome this situation, the F/M ratio is brought down by controlling following:

- Incoming effluent feed,
- Increasing the recirculation rate of activated sludge to ASB from Secondary Clarifier underflow,
- Amount of desluding based on excess sludge generation.

The F/M ratio is maintained around 0.2 to 0.4 day in the activated sludge basin with MLSS varying from 1500 to 3000 mg/ltr.

The high MLSS at ASB and higher sludge recirculation rate from sec. clarifier help in maintaining high BOD reduction efficiency even with fluctuation in incoming BOD load.

The process is monitored through sludge volume index (SVI) which is expressed as volume (in ml.) occupied by (one gm) suspended solid when allowed to settle in 1000 cc measuring cylinder. A value of 80 to 150 indicates a good settling sludge and value between 150 - 200 indicates that process needs immediate attention. With MLSS of 2500 mg/ltr when the clear liquor level in the measuring cylinder is 420 cc i.e. Vol. of settled sludge is 580 cc, the SVI works out to 232 ml/gm which indicates that MLSS has to be increased to achieve SVI value of less than 150 ml/gm by controlling the desluding process by controlling, sludge recirculation at ASB and /or by arresting the shock load, if any. To maintain energetic bacteria, the excess sludge to the tune of about 32 % by weight of incoming BOD_3, is discarded either to primary clarifier under flow sludge or to drying beds. To maintain high retention time, the consistency of secondary clarifier underflow sludge is maintained at about 0.8% to as high as 1.2%. Lower consistency of underflow sludge is also an indication of high SVI. The desludging % is varied based on MLSS to be maintained at ASB and mean cell residence time. The secondary clarifier underflow consistency can be increased to 0.8 - 1.0% by reducing sludge return ratio, reducing sludge wasting and raising D.O.

Table 6 : Results of ET Plant

Particulars	Unit	Inlet ETP	Inlet to ASB	Secondary Overflow	OPCB Norms
pH		6.0-9.0	6.5-8.5	7.1-7.5	7.0-8.5
Temperature	°C	38-48	33-35	31-34	-
Bio-Chemical Oxygen Demand	Mg/l	250-350	190-210	10-25	Max. 30
Chemical Oxygen Demand	Mg/l	1100-1300	650-750	250-310	Max. 350
Suspended Solids	Mg/l	900-1100	100-110	30-48	Max. 50

Mean Cell Residence Time

As the residence time of the cells in the system is increased, the settling characteristics of the biological flocs are enhanced, due to presence of polymers and slimes. Which promote formation of flocs, which settle by gravity.

The Mean Cell residence time of ASB cells at JKPM is about 10 days, which is well within recommended standard time of 5 – 15 days for activated sludge process. A operator checklist (Table-5) is attached for operating the ETP effectively.

ETP Performance

The effective running of modified ASP with cooling Tower leads to better control of BOD at 10 - 25 ppm, Temperature 31 to 34°C and suspended solid 30 - 48 ppm of discharge treated effluent. The details are given in Table - 6.

General Problem Occurs during the ASB Process

Foaming

Due to increase in pH due to spillage of black liquor and increase in fines due to spillage of pulp, a thick layer of foam develop at ASB after the aeration, at cooling tower as well as at ASB. This foam offset the D.O in the treated effluent and increases in load of Aerators. Addition of defoaming agent and or addition of alum helps to reduce foam. Sprinkling of water will also reduce foam. If pH is maintained at 7.2 to 7.4, the foaming tendency gets reduced. At higher MLSS (above 3500ppm) at basin, the foaming tendency of effluent gets minimized.

Sludge Bulking:

As the SVI value increases above 150 ml/gm, the activated sludge does not settling fast. Microscopic examination may show filamentous growth. This condition is known as sludge bulking(7). There is no firm rule for controlling the bulking of sludge either by excess dosing of nitrogen or by variation of Dissolved Oxygen (DO) at the basin or by controlling input BOD.

As per literature available, treatment of bio-sludge by dosing any of following chemicals along with reducing food to micro-organism ratio will set-right the bulking problem.[8]

- 3 to 10 mg/ltr of chlorine in the return sludge until SVI is less than 150 (9, 1 0)
- Addition of 5 to 6 mg/ltr Hydrogen Peroxide in the aeration basin until SVI is less than 120 (11)
- Addition of calcium hypo-chlorite @ 3M^3/day of 21-25 gpl Cl_2 at return sludge to basin at effluent processing rate of 1000 – 1100 M^3/day Hr.
- 'Fe' introduced into an activated sludge system improves the treatment efficiency in concentratious up to 30 mg Fe/ltr, while overdosing decreases COD removal. Addition of Ferrous sulphate to the tune of 10 mg/ltr i.e. 240 to 260 kg/day for 1000 – 1100 M^3/Hr effluent at inlet to ASB flow rate also help in eliminating sludge bulking.

Modern ECF & TCF Bleaching system experiences bulking problem throughout the world. In UK 60 % of the ASP experiences high value of SVI ie >200 and 50 % of ASP experience loss of solids. In Germany more than 27% of ASP plant experiencing bulking problem more than six months.[12,13,14,15,16]

Turbidity of secondary clarifier overflow

The secondary clarifier settling area is considered based on 50 to 150 kg Solids (MLSS) loading per day / M^2, based on average and peak flow respectively.

As per literature available, toxic shock loading may cause turbid effluent, which may be due to inactive protozoa. Reseeding from another plant may be necessary to overcome the situation. In case denitrification occur at secondary clarifier (nitrogen bubbling) and sludge is found to be rising in clumps, this problem can be overcome by

a. Increasing sludge return rate

b. Increasing DO in the aeration basin and / or

c. By reducing the sludge age.

Often floc rising occur due to temperature difference between liquid temperature at secondary clarifier at base and the underground temperature which result into convection current. High rate of recirculation of activated

Table 7 : Elimination bulking problem by $FeSO_4$ and Cl_2

Particulars	MLSS (gpl)	Settled Sludge Vol. in 30 minutes (ml)	SVI	Discharge SS (gpl)
Activated Sludge with bulking	2700	980	360	74
Ferrous sulphate	2700	750	280	45
Chlorine / Hypo / Bleaching Powder	2800	425	150	30

sludge along with consistent desludging may help to overcome the situation.

However, once the bacteria gets acclimatized to the new environment having uniform food to micro-organism ratio, a consistent BOD reduction efficiency of 90% (BOD from 200 mg/ltr to 20 mg/ltr) and above can be achieved with good floc settling rate by maintaining following :-

- Uniform pH,
- Uniform temperature,
- Uniform dosing of nutrients,
- Consistent supply of adequate quantity of oxygen by maintaining submergence of aerators (by maintaining uniform flow (17) of effluent) and
- Uniform rate of desludging by calculating excess sludge generation per day.

Color enhanced

Due to redox reaction at ASB, the colour of input to ASB effluent is lower than the Secondary clarifier overflow treated effluent.

CONCLUSION

Worldwide survey of ASPs is indicating the Bulking Problem more in ECF &TCF bleaching than the Chlorine and Hypo conventional bleaching. To achieve and maintain above conditions with varying seasons and varying quality of incoming effluent (w.r.t BOD, COD, SS, dissolved solids, temp. & pH etc.), the role of the operating and process controlling crew is very vital. Definitely improved control makes ASP more viable in ECF and TCF bleaching technology in pulp and paper industry where bulking problem occurs. Our new ET Plant deigned with foresight, installed with care and operated with precision will easily meet our environmental needs of coming decade.

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