HYDRODYNAMIC CAVITATION: A NOVEL METHOD FOR WATER AND WASTE WATER TREATMENT USING GREEN MEGA EFFICIENT REACTORS

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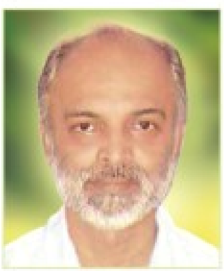

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Abstract

Effluent treatment/Water Treatment has always been a challenge in every industry, especially the Pulp and Paper industry. With the ever increasing stringency of effluent norms by the regulators, pressures from surrounding social inhabitants and as a conscious effort to be continually reduce environment footprint, it has become mandatory for Paper industries to keep the discharges in check. Of course, the treatment comes as a cost which the Paper mill has to incur but the cost has a multi-faceted concept to it. Most existing technologies require- large footprint, usage of chemicals, require dedicated equipment and cannot be added to existing system and have a heavy CapEx component attached. HyCator® Reactor System is an equipment based solution which disrupts the status quo by making mega efficient, environment friendly process reactors for fluid applications. These are easy to use and cost effective than existing solutions. Based on a technology which converts the kinetic energy of fluid into millions of targeted micro bubbles which are packed with extreme heat, pressure and turbulence and delivers it where it is needed keeping ambient conditions unchanged. HyCator® Reactors are custom designed and can be retrofitted into existing plants withminorpipelinemodifications.

Keywords: Water/Waste Water Treatment, Hydrodynamic Cavitation, Green Technology, Efficient Reactors, Case Studies(Shreyans Industries and others)

1. INTRODUCTION

Nowadays, due to the increasing presence of molecules, refractory to the microorganisms in the wastewater streams, the conventional biological methods cannot be used for complete treatment of the effluent. New developments in the variety of fields to meet the ever increasing requirements of the customer, have also led to the presence of new compounds in the effluent streams of processing plants, which are not readily degraded by the conventional effluent treatment methods[1]. For example, the earlier methods of sizing were by rosin and inorganic coagulants(Aluminium Sulfate or PAC) which have now given way to organic polymers for sizing application. The effluent generated in both cases will be different, so has to be the treatment process.Another case is that different impurities in raw materials,especially agro-based feedstocks, are posing newer treatment challenges because there are lot many technological changes happening at the source of generation and hence give rise to effluent loads which the current process may not be able to accept/treat. Hence there is a requirement of introduction of newer technologies to degrade these refractory molecules into smaller molecules, which can be further oxidized by biological methods.

One of the processes currently in use for reducing COD load is chemical oxidation, constituting the use of oxidizing agents such as ozone and hydrogen peroxide. However, the dosages of these chemicals are high and they are unable to achieve desired results because of lower rates of degradation as compared to the advanced oxidation processes. There is a huge gap wherein some technology can improve the efficacy of these chemicals and hence improve overall performance.

Another challenge in paper mills is that the huge resources have been spent in setting up existing ETPs that it may not be possible to completely change the process line from time to time. Hence, there is a need for a technology which can be retrofitted into the existing plant and also have minimal footprint. In this work we have tried to bring forth a technology which is based on Cavitation, explained henceforth. The paper goes through various types of cavitation, its advantages, applications and some case studies. Also, in this paper, we have dealt with hydrodynamic cavitation as that is the most easily scalable option, applicable to a various industrial applications and also has proven to be cost effective.

1.1. What is Cavitation?

Cavitation is defined as the phenomena of the formation, growth and subsequent collapse of microbubbles or cavities occurring inextremely small interval of time(milliseconds), releasing large magnitudes of energy[1].Figure 1 shows the Schematic presentation of the different phases of thecavity.Decreasing the pressure over the liquid to its vapor pressure generates vapor bubbles in liquid. This is also called as cavitation or cold boiling. When the pressure is brought back to normal pressure these vaporous bubbles collapse back in fluid with a bang to generate intense pressure and temperature at the point of collapse. Such intense conditions (9000 atmand 5000 K, intense turbulence) can bring about several physical and chemical transformations even when the bulk conditions are ambient. Due to such extremely high temperature, pressure intense turbulence; shockwaves are generated which are capable for floc deagglomeration, volatile solids degradation and increases mass transfer and microbial activities.

The four principle types of cavitation and their causescan be summarized as follows[3]:

Acoustic cavitation

In this case, pressure variations in the liquid are effected using sound waves, usually ultrasound (16 kHz–100 MHz). The chemical changes associated with the cavitation induced by the passage of sound waves are commonly termed as sonochemistry.

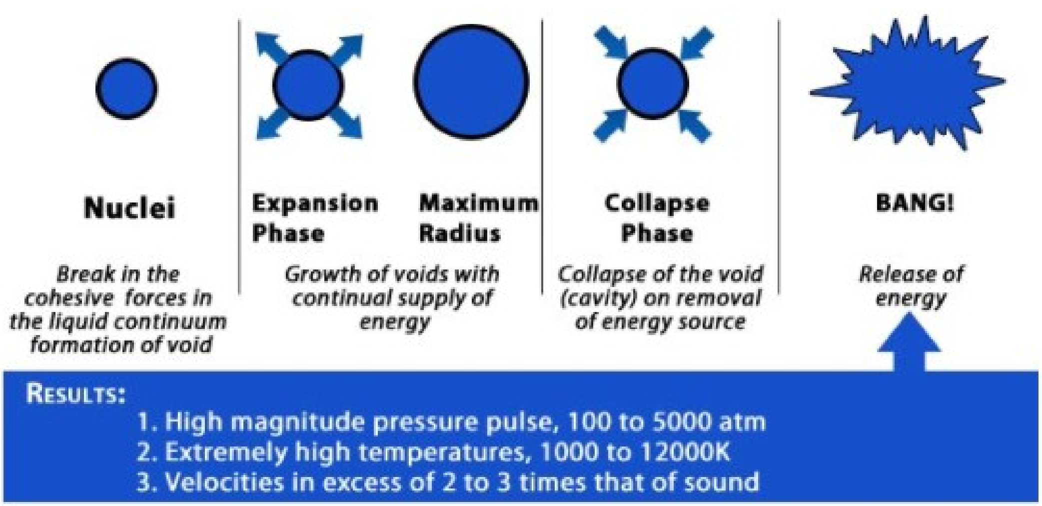

Fig 1-Stages of a Cavitation Bubble

Hydrodynamic cavitation

Cavitation is produced by pressure variations, which is obtained using the geometry of the system creating velocity variation. For example, based on the geometry of the system, the interchange of pressure and kinetic energy can be achieved resulting in the generation of cavities as in the case of flow through orifice, venturi, etc.

Optic cavitation

This is produced by photons of high intensity light (laser) rupturing the liquid continuum.

Particle cavitation

This is produced by a beam of elementary particles, e.g. a neutron beam rupturing a liquid, as in the case of a bubble chamber.

1.2. HydrodynamicCavitation : The potential it offers

Among the various modes of generating cavitation given above, acoustic and hydrodynamic cavitations have been of academic and industrial interest due to the ease of operation and generation of the required intensities of cavitational conditions suitable for different physical and chemical transformations. Hydrodynamic cavitation is of particular importance because it is easy to scale-up and proves to be effective over a wide range of industrial applications.It is worthwhile to overview different avenues where this technology can be exploited[3].

Water and Effluenttreatment

Cavitation can be used effectively for the destruction ofcontaminants in water because of the localized high concentrationof oxidizing species such as hydroxyl radicalsand hydrogen peroxide, higher magnitudes of localizedtemperatures and pressures and formation of transient supercriticalwater. The type of pollutants in the effluentstream affects the rates of the degradation process. Hydrophobiccompounds react with $OH^-$and H^- at the hydrophobicgas/liquid interface, while the hydrophilic speciesreact to a greater extent with the OH. radicals in the bulkaqueous phase. Optimization of aqueous phase organiccompound degradation rates can be achieved by adjustingthe energy density, energy intensity and nature andpropertiesof the saturating gas in solution.The variety of chemicals that have been degraded usingacoustic cavitation, though in different equipmentsandon a wide range of operating scales are p-nitrophenol,rhodamine B, 1,1,1 trichloroethane, parathion, pentachlorophenate, phenol, CFC 11 and CFC 113, o-dichlorobenzeneand dichloromethane, potassium iodide, sodiumcyanide and carbon tetrachloride among many others.

Cell Disruption

Cell disruption is one of the important and vital unit operationsinbiotechnology for the recovery of intracellularproteins/enzymes. This is an energy-intensive operation and hencethere exists tremendous scope for the developmentofcheaper and energy-efficient methods. Cavitation can beused effectively for the rupture of cells with energy requirementsas less as just 5 to 10% of the total energyconsumed using conventional methods. The intensityof the cavitation phenomenon can also be controlled so asto control the mechanism of rupture of cells, to selectivelyrelease the intracellular enzymes or enzymes present inthe cell wall. Lower intensity application of cavitationhelps in retaining the activity of the leached-out enzymesand also reduces the cost of operation. Hydrodynamiccavitation has been found to be much more energy-efficientcompared to acoustic cavitation and at the same timeapplicable at a larger scale of operation. This particular feature has lots of potential in Bio-Gas generation enhancement as shall be seen later.

Online Mixing

Mixing operation is the heart of most of the industrial processes and is even energy intensive. There are lots of chemicals to be dosed in the paper industry at various stages and the mixing times are very less. It so happens that with newer chemistries thathave come in play in the paper industry, sequencing of chemicals is done in a way that, the performance of the latter chemicals depends on how well the former chemical has performed. Example, before addition of retention aid, it is imperative to add a fixing agent for coagulation. Unless coagulation is proper, flocculation/retention will never be effective.Mixers based on Hydrodynamic cavitation ensures energy efficient, precise, microlevel, safe, online mixing even at very high flows.This results in Online uniform mixing, reduced dosage of chemicals due to uniform mixing, No need of pump for dosing and finally improved productivity.

1.3. Why do we need Hybrid Technologies?

The efficiency of the biological oxidation techniquesis often hampered by the presence of bio-refractorymaterials, though these are most conventionally usedand economical treatment strategies. On the other hand,though advanced oxidation processes promise degradationof almost all the contaminants, their use is hamperedby the fact that the knowledge required for the designand efficient operation of the large-scale reactors isperhaps lacking. Moreover, considering the economicalaspects, the use of advanced oxidation processes aloneas treatment procedure may not look lucrative. Thus, ahybrid method consisting of using advanced oxidationprocesses to reduce the toxicity of the effluent up to adesired level followed by biological oxidation is perhapsneeded for the future[2].In Figure 2, results for disinfection study of zoo-plankton in sea-water have been shown using various methods of disinfection. Although on a different note, we can see that hybrid methods lead to an improved performance, than standalone methods. In a study[4], it has been indicated that a real paper-mill effluent sample, pre-treated with ozone and then subjectedto biological oxidation resulted in enhancement in the bio-degradability-the COD in membrane-filtered samples was reduced by about 30%.Obviously, ozone reacted with the double bondsystems (aromatic rings) of the lignin components of the effluent.However, In another study[5], authors have indicated that even ozone/hydrogen peroxide combinationtechnique did notimprove the bio-degradabilitysignificantly, and use ofadditional oxidant

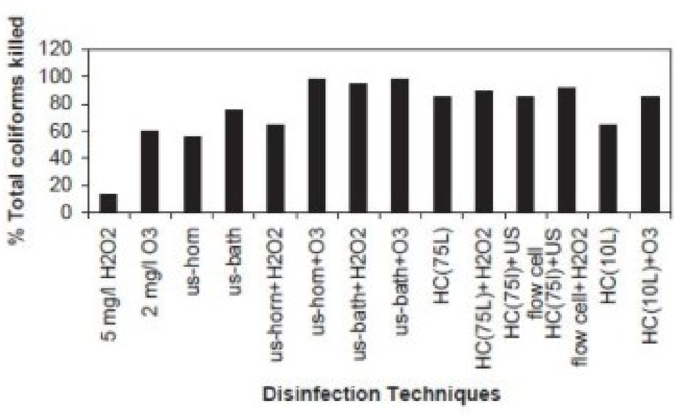

Figure 2 : % Total Coliforms killed by various techniques

in terms of UV light was observedto give best results for the effluents containing trihalomethanes.Thus, it indicates that certain minimum levelof selective oxidation has to be carried out in the pretreatmentstage so as to be really benefited from the useof advanced oxidation process. On the other hand,ozone/hydrogen peroxide addition in excess, though it sometimesresults in increased COD removal, should not bedone due to the toxic effects on the biological activity. Hence, it is necessaryto perform an optimization exercise on the effluentin question for deciding the oxidant dose so as to fulfil both of the above-mentioned conditions.

2. EQUIPMENTS AND ADVANTAGES FOR HYDRODYNAMIC CAVITATION

Hydrodynamic cavitation can be setup using basically 3 types of equipments[6]:

- Multiple orifices
- High speed homogenizer

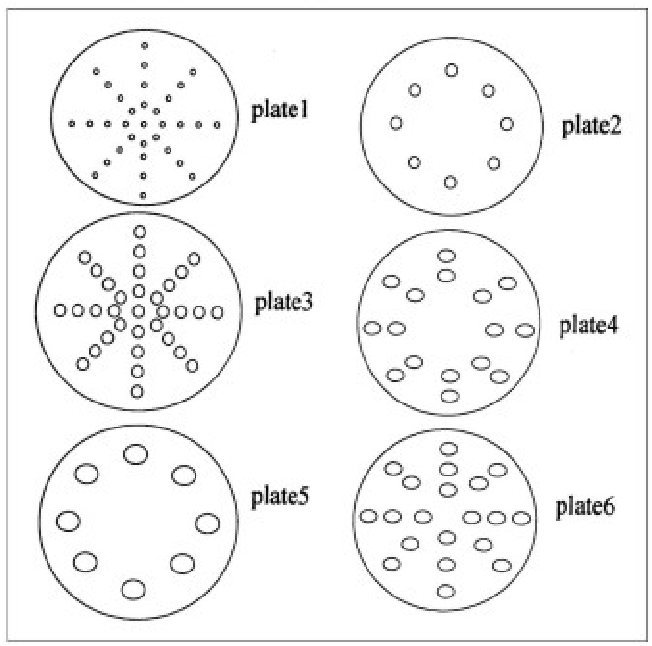

Figure 3 : Arrangement of different free areas on the plates

A lot of factors dictate which design is suitable to what application using a unifiedcriteria of cavitational yield based on the total energy consumptionand the energy efficiency of the system. However, the orifice plate configuration(different plates used are shown in Figure 3) is more efficient in termsof the dissipation of the energy, as well as in generating cavitationalactivity. In this work, we have restricted ourselves to practical application rather than reactor design.

2.1. Advantages of cavitation

Cavitation technology compares favourably with similar advanced oxidation processes (AOP) like Fenton's process, wet air oxidation, ozonation and hydrogen peroxide treatment and ultrasonic/ acoustic cavitation. These technologies require addition of more chemicals, which in turn add to the effluent load that need to be mineralized. Moreover, there is a requirement for higher bulk pressure and temperature as also longer processing times are needed on many occasions.

Advantages of cavitation technology include:

- A greener technology that does not necessarily need additional chemicals;
- Can be coupled with other AOPs, if required;
- Bulk temperature is ambient; bulk pressure is in range of 3-atm.; and
- Enhances performance of existing effluent treatment facility (improves efficiency of aerobic reactor, increases biodegradability of effluent (BOD:COD ratio), reduces COD of effluent etc.).

Similarly, cavitation based reactor systems also compare favourably with other standard mixing technologies like static mixing, jet mixing and stirred tanks:

- It can operate with lower overall pressure drops & hence lower net energy consumption;
- It does not need a holding tank or static containers, since mixing is done online. Hence, it has low footprint;
- Mixing takes place on micro-scale making it energy-efficient;
- Can be designed and operated practically for any pressure and flow rate; and
- Can be fabricated in any material of construction for high wear and tear, corrosive resistance and high pressure & temperature application.

3. APPLICATIONS AND CASE STUDIES

3.1. Application in cooling towers

The company has developed reactor systems for generating tailor made cavities suitable for particular applications like molecular breakdown especially useful in preventing biofouling in cooling tower water. Due to extremely high temperature & pressure and intense turbulence in the HyCator®: BFP(Bio-fouling prevention) Reactor System, shockwaves are generated that are capable of destroying microbes. The HyCator®: BFP Reactor System shown in Fig. 4 is a standalone unit, which will take its feed from cooling tower sump and the treated cooling water will be either discharged to the line going for process or back to cooling tower sump as a closed circulation.

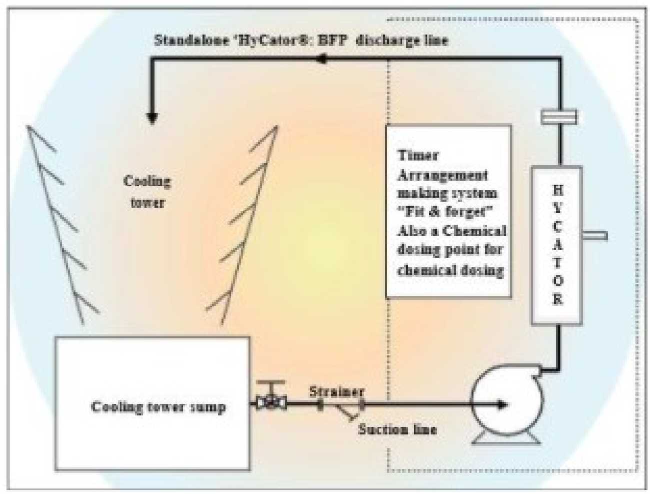

Figure 4 : Schematic of cooling tower circuit and standalone HyCator®: BFP Reactor System's installation

Potential benefits

The reactor system prevents biofouling and reduces the blow down to a very low value, which in turn, will reduce the make-up water rate. Once the frequency of make-up water is reduced, the addition of other chemicals will also reduce and other impurities due to addition of chemicals will also reduce significantly.

In general, for normal feed water quality the potential benefits include:

- Prevention of bio-fouling, corrosion problems and scale formation;

- Environmentally-safe: no chemicals added or unwanted residuals created by the process;
- No need of biocides;
- 40% reduction in consumption of dispersants and corrosion inhibitors;
- Reduced blow-down of water due to operation at higher cycles of concentration; and
- 40-80% reduction in consumption of blow-down water.

Case studies involving cooling tower

Bio-fouling prevention in cooling tower water

Chemical treatment cost was high and the plant management was under pressure to reduce water usage and discharge. Cycle of concentration was also low. A hard scale often formed in the summer season. The bacterial counts were 105 CFU/ml. HyCator®: BFP Reactor System was installed in the cool cooling tower circuit. A detailed study was conducted on the cooling tower system over a six month period to evaluate the performance of the device for disinfection, scaling, corrosion, cycles of concentration and heat transfer efficiency.

Make up water consumption was reduced by 30% and blow-down discharge reduced over 60%. Bacterial microbial counts became nil and cycles of concentration increased substantially. The results also indicated that the 'HyCator' BFP reactor system treatment performed well compared to the chemical treatment without the addition of any chemicals. In this particular case, dosage of anti-corrosion and scale prevention chemicals was also not required. Annual water saving exceed 3,600-m3.

High blow down water and bio-fouling

The main problem was high blow down water and bio-fouling. The cooling tower was operated at low cycle of concentration. After the installation of HyCator®: BFP Reactor System, the biocides dosing reduced to 10% and other chemicals (dispersant, corrosion inhibitor and anti-scalant) reduced to 40% of the original. The bacterial counts came down to under the permissible limit. Blow down was reduced by 40% and cycle of concentration was also marginally increased. Old scale was gradually removed and no new scales were formed.

High volume of make up and discharge water

The volume of make up and discharge water was high and it was operated in a low cycle of concentration. Bio-fouling was also high. Bio-fouling was fully controlled after the installation of HyCator®: BFP Reactor System. The scale and corrosion was also reduced over previous chemical treatment. Cycle of concentration also increased, resulting in reduction of 20% in make up water and 50% in blow down water.

3.2. Application in Effluent Treatment

Paper Mill Effluent (on going case)

A renowned North Indian Paper mill with Agro-waste as raw material was operating a standard configuration ETP-Equilisation tank, Anaerobic Digestion, Aerobic Treatment, Chemical Treatment and filtration. The mill was sometimes facing issues with (1) fluctuating DO levels (2) fluctuating loads due to which COD and BOD levels rose (3) residual color in the mill (4) wanted reduction in cost of treatment. The treatment scheme was studied and depending on the best available position, the HyCator®: MBD(Molecular Breakdown) was installed in the Aeration Tank-1(At-1) Recirculation. **The equipment was designed in such a way that it absorbs air automatically through a port.**It is always advisable to install HyCator® as upstream as possible in the process.

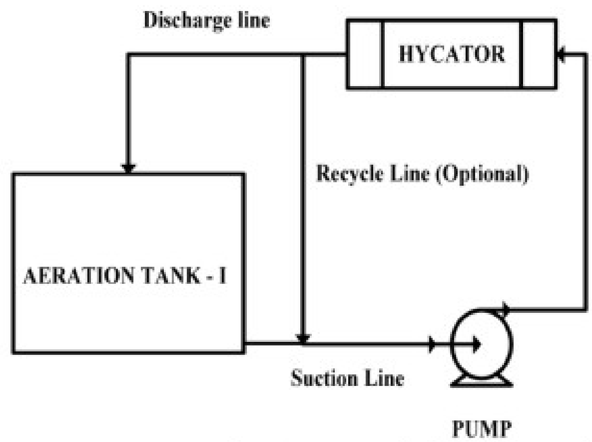

Figure 5 : Layout of HyCator installed at Paper Mill

The equipment had a total footprint of 1m^2 with the total assembly coming at less than 10m^{2}area. The total capacity of the AT-1 was 5000m3 and the capacity of the pump was 450m^3/hr with a 35m head. The main parameters that were checked were COD,BOD, DO and color.

Results and Discussion

(1) Period: April-May: the equipment was started in May and compared with results of April.

As shown in below Figure 6, there is a marked increase of % reduction in CODat outlet of AT-1. Almost 17-20% increase in the reduction of COD was observed. Also, from the data of dissolved oxygen(DO), it is clear that there is substantial improvement in the DO(mg/L). It is worthwhile to note that these are the results when the temperature almost increased by 7-8°C due to summer season.

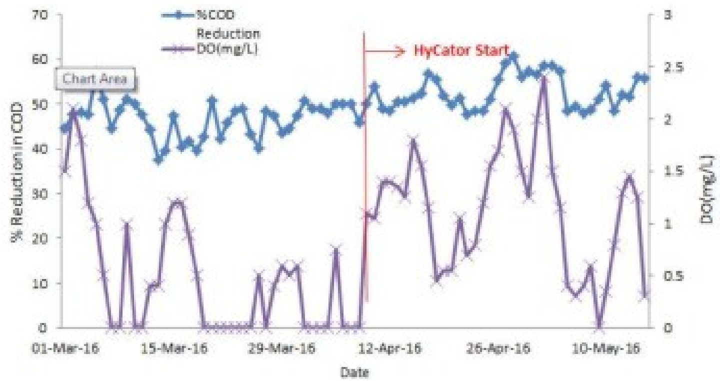

Figure 6 Performance for the period of April-May

(2) Period: June-July: there equipment was turned off in June and turned on for July

This time, again, as can be seen in Figure 7, the COD at

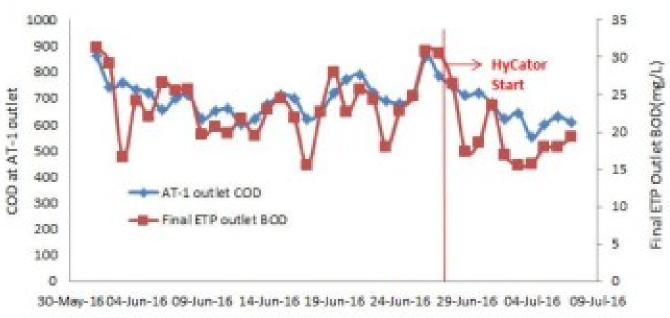

Figure 7 Performance for the period June-July

The Table below shows working cost of HyCator®

outlet of AT-1was reduced almost the same amount 15%. For the same period, BOD at final outlet(before discharge) was recorded and it was found to be reduced by 20%- 23ppm in June to 18.1 in July(uptil mid-July only). This shows that the results from the application are translated to the final outlet.

Working Cost of HyCator

Parameter	Quantity	Units
Pump Power	75	kW
Cost of Electricity	8	Rs./kW
Total Cost of Pumping	600	Rs./hr
HyCator Operating Cost	0	Rs.
Air injection cost	0	Rs.
Pump maintenance cost	Negligible	Rs.
Volume handled	450	m^3/hr
Total cost per unit volume of effluent handled	1.33	Rs/m^3

Table 1: The operating cost of HyCator

Improvement in COD reduction capacity of bioreactor system

A Common Effluent Treatment Plant near Mumbai was operating two bio-towers (A & B) for reducing the COD of partially treated effluent streams. COD reduction in biotower A was 40% and in biotower B was 34%, but even with this the COD of exit stream of ETP was not under the specified limits of discharge. Other alternatives to achieve this were to increase the size of bioreactor or the residence time, i.e. reducing throughput or ozonation etc. All the alternatives required substantial modifications in the existing system or needed addition of chemicals.

HyCator®: MBD Reactor System installed in the inlet effluent stream of one of the biotower (B) for increasing the biodegradability of the effluent. A detailed study was conducted on the biotower system to evaluate the performance of the installed device for COD reduction, bio-refractory breakdown & oxidation, disintegration of biomass and intensification of bio-reactors. The COD reduction in the biotower B increased from 34% to 54%, at a mere additional operational cost of Rs. 0.32/m^3. The exit COD was reduced to within discharge limits.

Conversion of non-biodegradable ethylene oxide to biodegradable glycols

Ethylene oxide (EO) is released during tanker unloading, which is arrested by scrubbing it with water. EO being highly soluble in water, antimicrobial and poisonous, cannot be taken to regular effluent treatment plant (ETP) as it will destroy the biomass present in the bioreactor. In this case, 2-m3 of water containing 20,000 ppm of EO is generated and needs to be treated before it could be discharged. Conversion of EO (non-biodegradable) to glycols (biodegradable) by conventional process requires very high temperature (>150OC) and high pressure (30-kg/cm2). HyCator®: MBD Reactor System was recommended to treat this effluent stream. After successful pilot trials, a plant scale HyCator®: MBD Reactor System was custom made for reducing the EO content cost effectively from 20,000-ppm to less than 3,000-ppm in just 16 hours. By using HyCator®: MBD Reactor

System and no additional chemicals, EO was converted to a readily biodegradable material, which is further easily mineralized in a conventional bioreactor in the existing ETP.

CONCLUSIONS

- With presence of complex molecules in the effluent water, conventional biological methods will not be sufficient to mitigate these from waste water, hence it would be imperative to introduce Advanced Oxidation/Hybrid processes for treatment.
- Cavitation appears to be a promising technique for water treatment. It is an energy efficient process and hence can be considered as a potential technique for a large-scale water treatment scheme. Pretreatment with hydrodynamic cavitation reduces the consumption of the disinfecting chemicals such as hydrogen peroxide, ozone, etc., substantially.
- HyCator® reactors offer multiple advantages in terms of-low CapEx, minimum foorprint, clean technology, easily retro-fitted and reduces chemical usage.
- The treatment on real time Pulp and Paper Effluent has shown substantial proof-of-concept about the applicability and possible benefits of the HyCator® technology. Many other applications in Pulp and Paper industry can be exploited, namely- Bio-Gas generation, Cooling Tower Disinfection, Chemical(Ozone/Peroxide/Polymer) dosing.
- The technology is still at a development stage and needs further applications in the industry before it can replace conventional treatment methods completely.

4. ACKNOWLEDGEMENTS

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