Hydrodynamic Cavitation Based HyCator® Reactor System for Physico-chemical processes intensification

Dr. Aniruddha B. Pandit*
HyCa Technologies Pvt Ltd, Mumbai

Cavitation is a physical phenomenon associated with three aspects: formation, growth and collapse of a vapor or gas-vapor bubbles within the body of a liquid due to variations in local static pressure.

Decreasing the pressure over a liquid and bringing it to its vapor pressure at the operating temperature generates vapor bubbles in the liquid. When the pressure is brought back to normal pressure, these vaporous bubbles collapse with a bang to generate intense pressure and temperature at the point of collapse (Fig. 1). Such intense conditions (5,000 atm and 12,000°K, intense turbulence) and resulting shock wave can bring about several physical, chemical & biological transformations, even when the bulk conditions are ambient.

Mumbai-based HyCa Technologies Pvt Ltd has developed the technology to create and collapse precisely tailored cavitation bubbles to modulate the pressure, temperature and turbulence conditions by means of controlled variations in the pressure of fluid. This article describes few case studies where the company's 'HyCator®' brand of reactor systems were gainfully employed in effluent treatment plants (chemical transformations) and particle size reduction (Physico-chemical transformations) application.

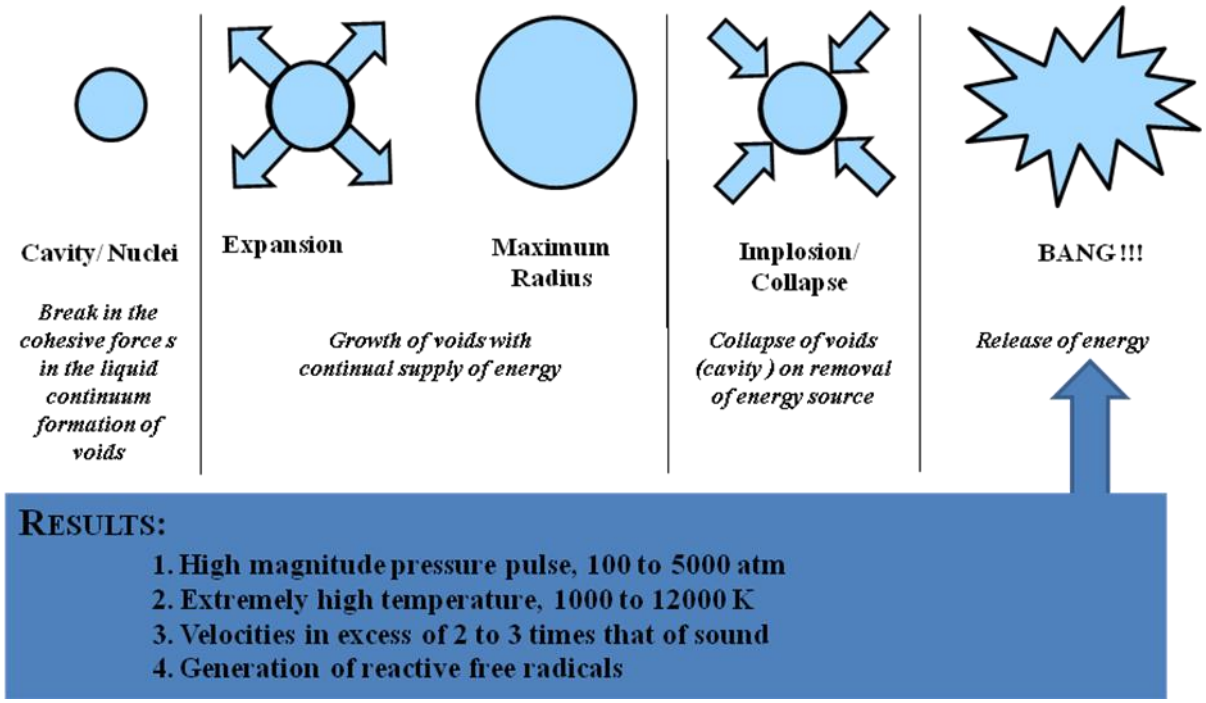

Figure 1: Principle: Hydrodynamic cavitation

Aniruddha B. Pandit* (FNAE, FNA)
Chairman
HyCa Technologies Pvt Ltd,
176, Udyog Bhavan,
Sonawala Road, Goregaon (E), Mumbai-400063, India
Mob:- +919820408037
Email:- dr.pandit@gmail.com

Main features of HyCator®: Reactor Systems

Minimum footprint	Can be easily fitted in congested places, makes retrofitting possible
Reduces chemicals usage	Less polluting
Highly efficient	Uses lesser energy for same work
Saves water	Saves this scarce and costly resource
Speeds up processing time	Increases plant capacity with same resources
Can handle large flows	Industrial scale operations
Technology allows for retrofitting	Makes existing plants more viable
Can combine with other technologies	Makes existing plants more viable
Low Cost	100 percent depreciation in first year, extremely attractive paybacks

The 'HyCator®' brand of hydrodynamic reactor system can be used to intensify various physical, chemical and biological processes occurring in different applications as follows-

- Effluent pre-treatment
- Nano-emulsion preparation
- On-line mixing of fluids, slurries & gases
- Biogas generation enhancement
- Cooling tower water disinfection
- Ballast water treatment

Out of all the above applications here we have discussed two applications of HyCator® namely in effluent treatment plants (Physico-chemical transformations) and nano-emulsion preparation (physical transformations) application.

I. Application in effluent pre-treatment

(Physico-chemical process intensifications)

The HyCator® reactor system has been used to intensify various physico-chemical processes occurring in effluent treatment plants in energy and cost-effective manner.

In HyCator® Reactor System, the cavity undergoes rapid volumetric implosions/ oscillations and produces the high turbulence shear stress in the surrounding liquid. Thus, the cavitation occurring in the system can produce several effects, such as high velocity liquid jet, shock wave and turbulent shear stress, which are responsible for break-down of the larger bio-refractory pollutants into smaller one which leads to increased molecular activation of the pollutants for easy mineralisation/ oxidation and also increases biodegradability of the same which results into a reduction in retention period of effluent in bio-towers. Also, in HyCator® Reactor System the energy released during cavity collapse is harnessed for the generation of $OH\cdot$ free radicals by the dissociation of water molecules which are responsible for the oxidation of organic compounds in the effluent. Hence with the use of HyCator® Reactor System we can carry out pre-hydrolysis and oxidation of bio-refractory pollutants in a single step without addition of any external oxidizing chemicals.

Case Study: 1

A Common Effluent Treatment Plant (CETP) near Mumbai was operating two bio-towers (A & B) for reducing the COD of partially treated effluent streams (Fig. 2). COD reduction in biotower A was 40% and in biotower B was 34%, but even with this the COD of the exit stream of ETP was not under the specified limits of discharge. Other alternatives to achieve this were to increase the size of the bioreactor or the residence time in the bio-tower, i.e. reducing throughput or ozonation etc. All these alternatives required substantial modifications in the existing system or needed addition of chemicals.

Bio-tower or a tower trickling filter sometimes used as part of secondary treatment process in industrial or municipal waste water treatment process. Basically, Bio-tower is a housing in which wastewater trickles through a bed of slime covered media and is treated by the biological oxidation done by the aerobic microorganisms in the slime layer, utilizing the organic pollutants in the wastewater as a food source. Tower trickling filter media or packing provide the surface over which microorganisms grow. If microorganisms are overfed, the aerobic bacteria die. This leaves anaerobic bacteria to take over and begin producing H_2S (hydrogen sulfide) which smells like rotten eggs. Therefore we need to control COD of effluent going to Bio-tower to avoid its proper functioning.

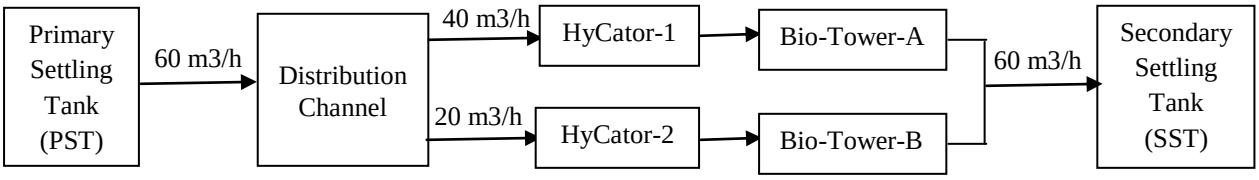

Figure 2: Layout of CETP

2 A) HyCator® at Bio-tower A
Flow rate = 40 m^3/hr
Pressure 3.0 kg/cm^2
Line size = 4”
Qty- 1.0 no.

2 B) HyCator® at Bio-tower B
Flow rate = 20 m^3/hr
Pressure 3.0 kg/cm^2
Line size = 2”
Qty- 1.0 no.

HyCator® Reactor Systems were installed in the inlet effluent stream of each of the bio-tower (A & B) (Fig. 2A & 2B) for pre-hydrolysis and oxygenation to increase the biodegradability of the effluent in each of the biotower. A detailed study was conducted on the each bio-tower system to evaluate the performance of the installed systems for COD reduction, bio-refractory breakdown & oxidation, disintegration of biomass and intensification of bio-reactors.

As shown in table 1 it is observed that we are able to reduce the COD of bio-refractory effluent by 53% and 38% at bio-tower A & B respectively with single circulation through HyCator® Reactor System. Since overload of COD on each bio-tower reduced with pre-hydrolyisis and pre-oxidation of

effluent using HyCator® Reactor System the bio-tower performance increased by 30% at a merely additional operational cost of Rs. 0.32/m3. As well as HyCator® Reactor System pre-treated effluent taking less retention period for biological oxidation in bio-towers and also the problem of overfeed of microbes and foul smell associated with it was ultimately eliminated.

Table 1: COD reduction profile before and after of HyCator®: Reactor Systems at each Bio-tower

Day	HyCator® at Bio-tower A		Reduction in COD (ppm)	Percentage Reduction	Average % COD reduction
	Inlet COD (ppm)	Outlet COD (ppm)			
1	724	305	419	57.87	**53.81**
2	555	333	222	40	
3	715	333	382	53.43	
4	634	268	366	57.73	
5	675	270	405	60	
Day	**HyCator® at Bio-tower B**		**Reduction in COD (ppm)**	**Percentage Reduction**	**Average % COD reduction**
	Inlet COD (ppm)	**Outlet COD (ppm)**			
1	583	333	250	42.88	**38.04**
2	516	316	200	38.76	
3	560	352	208	37.14	
4	413	344	69	16.71	
5	413	344	69	54.72	

Benefits gained by CETP from HyCator® Reactor System

- Pre-hydrolysed and pre-oxygenated effluent feed to bio-tower which increased its efficacy
- Approximately 40-50% COD reduction and 30-50% enhancement in COD reduction rate
- Increase in bio-tower performance
- Continuous operation at varying COD load
- COD reduction in outlet stream which reduced the load on the polishing aerobic treatment
- Improvement in biodigestion & composting etc.
- Low or no maintenance needed
- Low treatment cost

Advantages of HyCator® Reactor System

- A greener technology that does not necessarily need additional chemicals;
- Can be coupled with other Advance Oxidation Processes, if required;
- Bulk temperature is ambient; bulk pressure is in the 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.).

II. Application in the preparation of nano-emulsion:

(Physical process intensification)

The company has also developed an innovative product HyCator® Reactor System, by mastering the art of stimulating formation and collapse of cavities in the required manner and on the desired scale, which can carry out several physical processes like particle size reduction and nano-scale emulsion preparation.

As shown in figure 3, HyCator® reactor system is fine tuned for generating tailor made assemytric cavities to carryout physical effects like grinding of particles up to nano level. During the asymmetric collapse of the cavity flow from the bottom of the bubble is retarded by the presence of the solid boundary and form the micro jet of velocities up to 200-300 m/s. Cavity grows and collapses within single cycle. Size reduction is because of shockwaves and microjets generated after cavity collapse. Particles/ droplet size reduction is due to fluid shear in the vicinity of oscillating cavities. Length scales associated with cavitation is in the order of a collapsing cavity i.e. few microns to few nanometers, whereas in conventional size reduction equipments the turbulent length scales is of the order of few mm. Thus, cavitation is known to dissipate energy on the length scales required for size reduction which makes cavitationally induced size reduction to nano scale level. This makes cavitation based HyCator® reactor system much more energy efficient compared to conventional methods of size reduction.

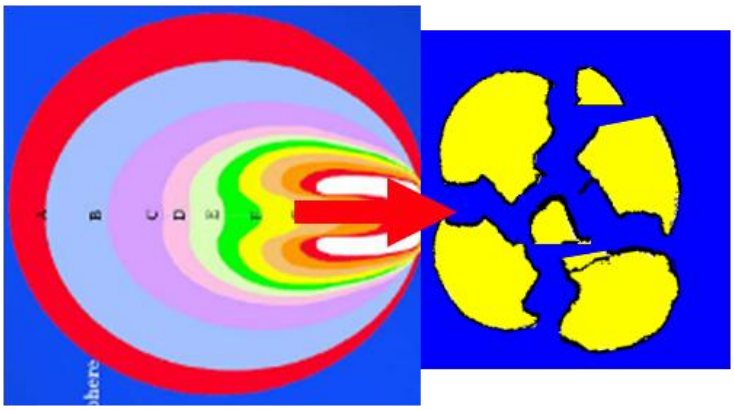

Figure 3. Schematic diagram of asymmetric cavity collapse for particle breakdown

Case Study: 2

A renowned Mumbai based FMCG company was required to develop a process of preparation of nano-suspension emulsion from a large nano sized (5900.0 ± 100.0 nm) suspended particles. They wanted a nano-suspension with a compact size distribution and that too as small as possible. Other alternatives to achieve this particle size distribution were to procure an extra grinding mill to decrease the size and to increase the residence time of grinding/ emulsification, change the surfactant etc. All the alternatives required substantial modifications in the existing system and huge investments and/ or altered the final composition. Also, the system needed to produce nano-emulsion on one ton scale.

A scaled-up HyCator® Reactor System was installed in one of the unit to prepare the nano-emulsion. A detailed study was conducted on the existing system to evaluate the performance of the installed device for droplet size reduction and intensification of the process.

Figure 4: Scaled-up HyCator® Reactor System

A HyCator® Reactor System having operating flow rate 10 m^3/hr, pressure operating at 10 bar was installed on a 1 m^3 reaction vessel. Initial particle size of feed material was 5900.0 ± 100.0 nm which was unacceptable and it contributed to the roughness of the final product. To enhance the lustre of the material and to reduce the droplet size, we treated the said material through HyCator® Reactor System as shown in figure 4. In our system, we allowed a controlled asymmetric implosion of cavities, resulting in the generation of mechanical shock, micro jets and high turbulent shear stress in the surrounding liquid which helped us to disintegrate the larger droplets. During the treatment, we collected the sample at regular interval of time (number of passes) and analysed using Malvern Particle Size Analyzer to check the performance of installed system. A graph of particle size vs. number of circulations/ passes of material through the HyCator® Reactor System is plotted as shown in Figure 5.

From figure 5 we observed that with increase in circulation of material through HyCator® Reactor System up to 18 passes particle drop size reduction is observed from 5900 nm to 250 nm. This particle size reduction trend is due to repeated treatment of material through our HyCator® system which contributed to the disintegration of the drop size by mechanical shock and turbulence created by repeated asymmetric cavity implosion. With further circulations we did not observed any significant droplet size reduction and it is due to a cushioning effect occurred by particle size reduced material by which the formed cavities could not be imploded with a significant intensity as that of before. The 90% drop size reduction was achieved in 50 minutes at a mere additional operational cost of Rs. 25/m^3 and again the system does not need any maintenance. Lustre of the treated material increased substantially and matched the client's requirement and company saved huge investment involved in other alternative solutions.

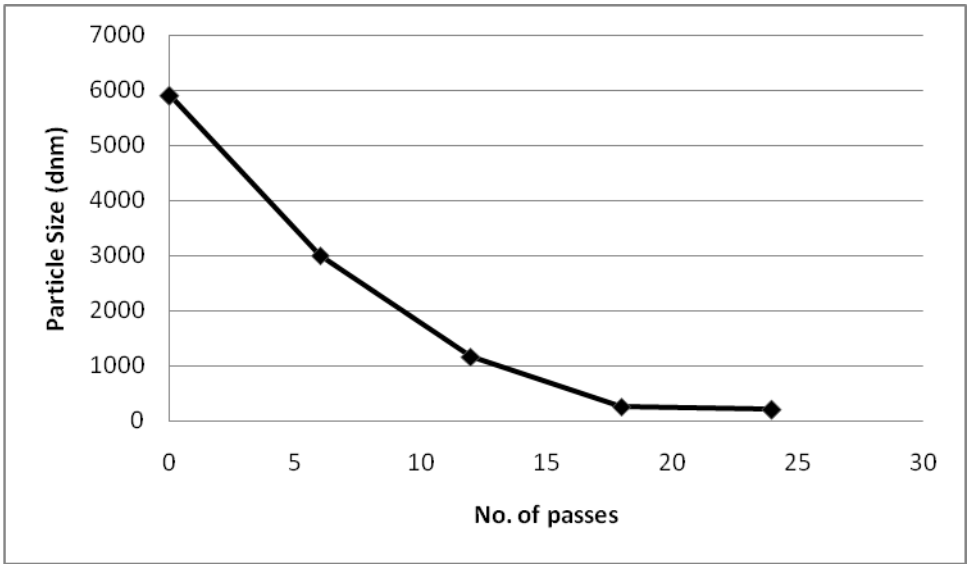

Figure 5: Graph of droplet particle size Vs no. of circulations/ passes through HyCator®

Benefits gained by the company from HyCator® Reactor System

- Got desired particle size reduction/ product lustre
- Less period of operation compared to other methods
- Cost savings due to reduction in energy consumption
- No additional hardware/ auxiliary equipment requirement

Advantages of HyCator® Reactor System over above technologies

- Uniformed particle drop size reduction
- Online grinding possible
- Can operate at lower pressure drops
- Does not need any special equipment since size reduction is done online. Hence, it has low foot print
- Need not to use separate auxiliaries hence size reduction is energy efficient
- Can be designed and operated practically for any pressure and flow rate
- Requires no operational supervision and maintenance.
- Stream can be easily bypassed when required.
- Time saving

Concluding remarks:

- Hydrodynamic cavitation based HyCator® Reactor System can be used to carry out physico-chemical process intensifications.
- HyCator® is can be utilized for pre-hydrolysis and pre-oxidation of effluent.
- It does not use any external chemicals for effluent pre-treatment hence green rated product.
- HyCator® can be utilized as a pre-treatment system in every effluent treatment plants.
- HyCator® enhances the performance of secondary treatment by reducing effluent load as well as retention period.
- HyCator® can be applied for producing nano-emulsions.
- HyCator® gives desired effects in terms of final size as well as uniformity in nano-emulsion preparation application.
- HyCator® requires less maintenance.
- HyCator® is energy and cost efficient.

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