Hydrodynamic cavitation technology: Industrial applications

Prof Aniruddha B. Pandit

Pratik P. Sangave, Aniruddha B. Pandit, Anjan C. Mukherjee
HyCa Technologies Pvt Ltd, Mumbai

Cavitation is a physical phenomenon associated with three aspects: formation, growth and collapse of vapor or gas-vapor bubbles within the body of a liquid due to variations of 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, in cooling towers, particle size reduction and biogas production enhancement application.

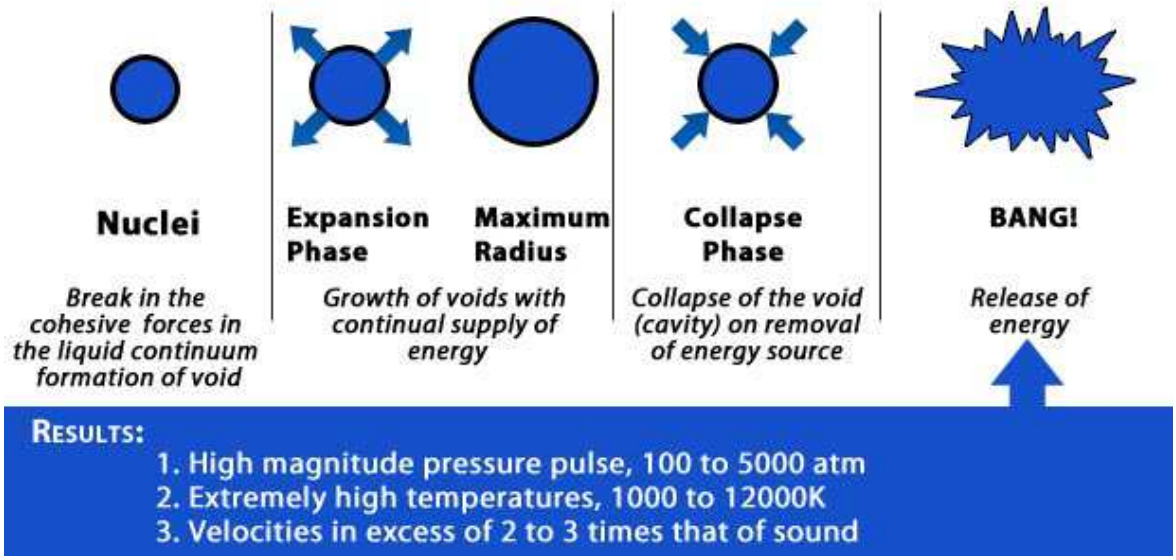

Fig. 1: Principle: Hydrodynamic cavitation

I. Applications in effluent pretreatment

The 'HyCator®' brand of reactor system has been used to intensify various physical, chemical and biological processes occurring in effluent treatment plants in energy and cost-effective manner.

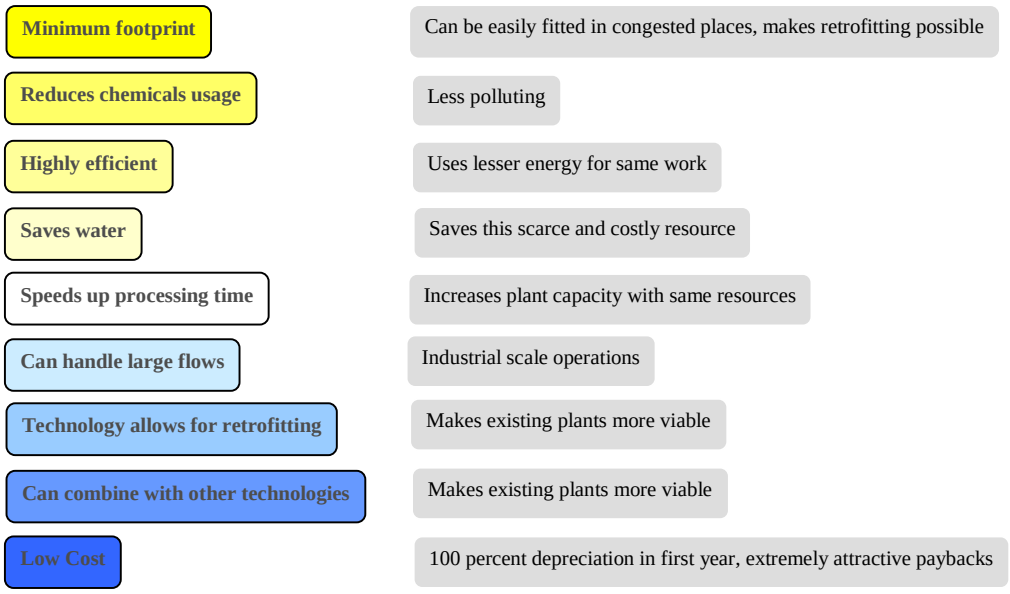

Fig. 2: Main features of HyCator®: Reactor Systems

These reactor systems can be retrofitted to any existing effluent treatment plant to make the later more effective and efficient by reducing pretreatment time and costs, as well as the reduction in the usage of chemicals in an environment friendly way (Fig. 3).

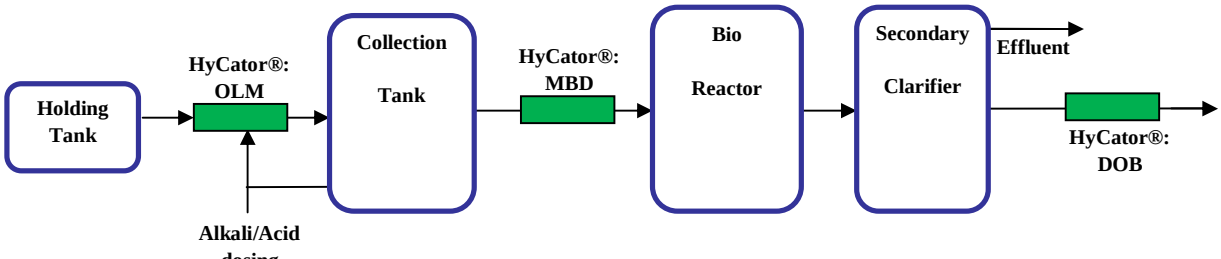

Fig. 3: Retrofitting standalone 'HyCator' reactor system into existing facility

The different types of reactor systems include:

The HyCator®: OLM Reactor System generates tailor-made cavities for micro-level mixing. Length scales associated with cavitation is in the order of the diameter of a collapsing cavity, i.e. few nanometres to few microns, whereas in conventional mixers the turbulent length scales is of the order of mixing element, i.e. few centimeters. Thus cavitation is known to dissipate energy on the length scales required

for mixing which makes cavitationally induced mixing a micro-level mixing. This makes cavitation based HyCator®: OLM Reactor System much more energy efficient compared to conventional methods of on-line mixing.

In HyCator®: MBD Reactor System, where the energy released during cavity collapse is harnessed for the generation of OH free radicals which are responsible for the oxidation of organic compounds in wastewater. The wastewater after passing through the reactor – has much reduced COD levels and biodegradability is also enhanced due to break-down of the larger bio-refractory pollutants.
For HyCator®: MBD Reactor System used for effluent pretreatment, we first carry out the pilot trials on client's organizations' most representative effluent samples at our lab, sets the trial protocol and once achieving success we request client to witness the trials. Conducting the trials as per our standard pilot trial protocol and conveying you its analysis results will take around 8 (eight) days. Based on results and your comments on the same; further course of action we decide. Without pilot trials we would not able to provide you a full scale solution.

HyCator®: DOB Reactor System helps to disintegrate biomass in energy- and time-efficient manner. This increases the activity of the biomass, thereby reducing the generation of waste activated sludge and speeding up further processing which are many times controlled by intracellular enzymes which are not easily accessible to the pollutants.

Advantages of cavitation

Cavitation technology compares favorably 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 favorably 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.

Benefits of 'HyCator' DOB reactor system includes:

- Increases the activity of microbes by partial disintegration and total deagglomeration of biomass resulting in high rate of reactions for acidogenesis, acetogenesis & methanogenesis;

- Floc deagglomeration leads to better mass transfer;
- Minimum 8% and a maximum upto 30% increase in digester performance;
- Treatment of huge volumetric sludge streams;
- Continuous operation at varying sludge properties; and
- Stability against reactor blocking (sludge impurities).

Case studies in effluent treatment

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/m3. The exit COD was reduced to within discharge limits.

COD reduction of viscous, partially polymerized glycerine foot

A company was having trouble in treating a viscous, partially polymerized glycerine foots (distillation residue from glycerine distillation) stream. Although, the stream was biodegradable, it would need extremely long hydraulic retention time (HRT) if treated in regular aerobic reactors, as it was partially polymerized and had high COD (170,000 to 50,000 ppm). Other options available were to use a bioreactor, but due to high viscosity and long chain molecules, the residence time (volume) required in the bioreactor would have been very large.

HyCator®: MBD Reactor System was recommended and designed for treating the same. Almost 70% to 95% reduction in COD was achieved cost effectively without any addition of chemicals like H_2O_2, which would otherwise have been required to partially reduce the COD in conventional ETP. The effluent stream was not required to be diluted, thus considerable water saving was also achieved.

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 (>150^{O}C) 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.

II. 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 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.

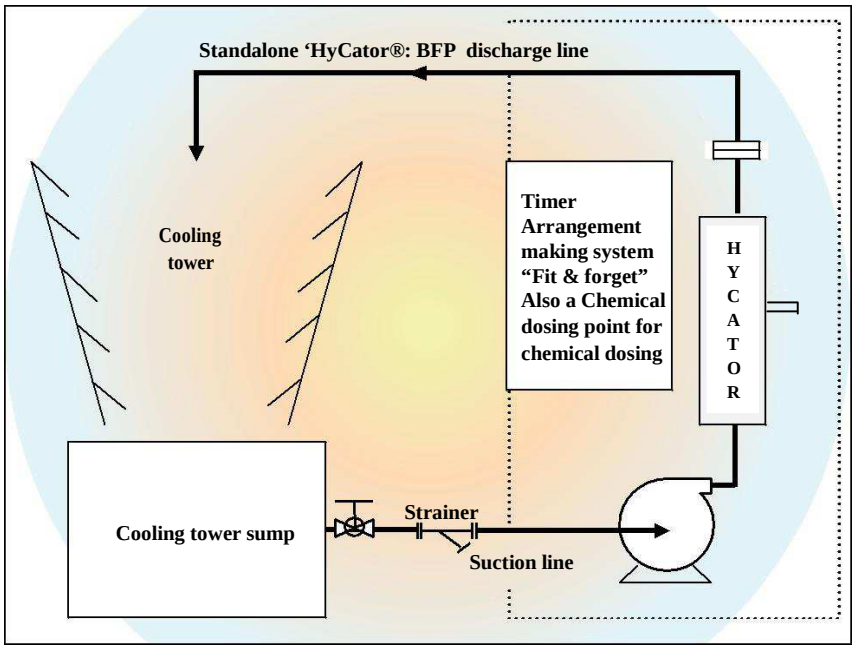

Fig. 4: Schematic of cooling tower circuit and standalone HyCator®: BFP Reactor System's installation

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.

III. Application in particle size reduction

The company has developed innovative product HyCator®: PBD Reactor System, HyCa Technologies have mastered the art of stimulating formation and collapse of such bubbles in the required manner and on the desired scale. HyCator®: PBD reactor system is fine tuned for generating tailor made cavities to grind the particles up to nano level. 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®: PBD reactor system much more energy efficient compared to conventional methods of size reduction.

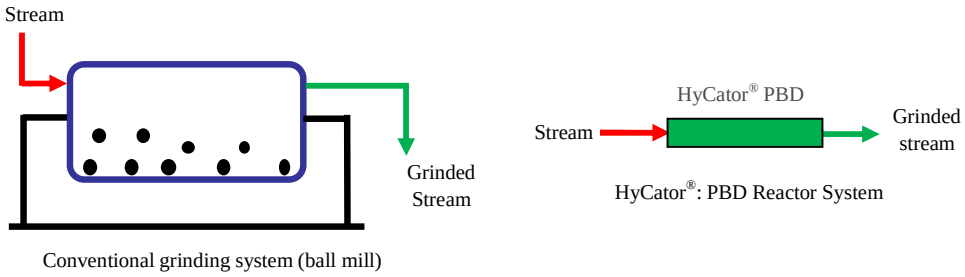

Figure 5: Retrofitting HyCator®: PBD Reactor System into existing facility

As shown in fig. 5 standalone HyCator®: PBD reactor system can be fitted with minimal alterations in the existing system and be completely bypassed when needed. It requires minimal footprint and is ideal for place where safety issues are very stringent as an entire operation is concealed.

Comparison of Cavitation with other standard size reduction technologies

Other similar size reduction technologies are

1. Colloid mills (e.g. ball mills, bead mills)
2. Disc mills
3. Jet mills
4. Rotor-stator mixers/high-pressure homogenizers

These technologies face following demerits like

- Requires a special equipment
- Higher energy requirement
- Operation is not cost effective in size reduction equipment
- Particle size may not be uniform

Advantages of HyCator®: PBD Reactor System over above technologies

- 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
- Can be fabricated in any Material of Construction for high wear and tear, corrosive resistance and high pressure & temperature applications.

Economic Benefits of HyCator®: PBD Reactor System

- Cost savings due to reduction in energy consumption
- No additional hardware requirement

Other benefits

- Can be easily installed and needs only fitting it in bolted flanges at the required location.

- Requires no operational supervision and maintenance.
- Stream can be easily bypassed when required.
- Time saving

Case study of HyCator®: PBD Reactor System

Preparation of nano-suspension using HyCator®: PBD reactor system

A renowned Mumbai based FMCG company was having trouble in the process due to large nano sized (5900.0 ± 100.0 nm) suspended particles into the processing system and they wanted a absolute nano-suspension with particle size distribution 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 etc. All the alternatives required substantial modifications in the existing system.

HyCator®: PBD reactor system was installed in one of the unit to prepare the nano-suspension. A detailed study was conducted on the existing system to evaluate the performance of the installed device for particle size reduction and intensification of process. By using HyCator®: PBD reactor system, the particle size was reduced up to 300.0 ± 10.0 nm. The 90% particle size reduction was achieved at a mere additional operational cost and it does not need any maintenance.

Pigment grinding using HyCator®: PBD reactor system

One of the Gujarat based renowned dyes and pigment manufacturing company was using a ball mill for pigment grinding to reduce particle size from 0.66 micrometer to 0.53 micrometer. They were getting substantial high manufacturing cost of respective pigment due to huge power requirement for ball mill to achieve desired particle size as well as time required for this unit operation was also high.

Volume (batch size)- 8844 lit
Pump flow rate- 300 lit/hr = 50 lpm
Motor power- 75 Hp = 56 kW (at 60% efficiency)

Sr. No.	Label	Cumulative treatment period required (hrs)	No. of passes	Mean dia. 90% (µm)	Power Consumed (Kw. hrs)	Operating cost (Rs. Per liter) @ 5 Rs. /kw.hr
1	Sample (Initial)	0	0	0.66	-	-
2	Particle size reduction using bead mill	144	9	0.53	8064	40320.00
3	Particle size reduction using HyCator®: PBD	59	20	0.53	3301	16506.00

Table 1: HyCator®: PBD Reactor System Vs Bead Mill for pigment grinding application

HyCator®: PBD reactor system was proposed for grinding of pigments and organization has achieved desired particle size reduction with 2.5 times lower power and treatment period that of previously required ball mill and substantially saved time and manufacturing cost as shown in table 1.

IV. Application in biogas generation enhancement

HyCa Technologies has also developed HyCator®: BGG Reactor System to enhance biogas generation from anaerobic biodigesters. For efficient utilization of feed in biodigesters, the disintegration pretreatment of digester feed process using advance technology is needed. HyCator®: BGG Reactor System has shown a positive effect on the degree and rate of digester's feed hydrolysis and ultimately on anaerobic digestion and has resulted into biogas production enhancement. By applying hydrodynamic disintegration a controlled lysis of anaerobic digestive cells occurs in minutes instead of days. The intracellular and extracellular components are set free and are immediately available for biological degradation which leads to an improvement in the subsequent anaerobic process. The cell of the activated sludge micro-organisms rupture and aids the digestion process leading to increased biogas production. Also, HyCator®: BGG Reactor System helps to disintegrate the larger size pollutant molecules into substantial smaller one by the shear force, mechanical shock and turbulence generated locally which help to degas the system so that pretreated feed gets easily digested further into digester i.e. biodigestability of the feed is increased which also contribute to the enhancement in biogas production.

Potential Benefits HyCator®: BGG Reactor System:

- Increases the activity of microbes by disintegration of biomass resulting in high rate of reaction for acidogenesis, acetogenesis & methanogenesis
- Floc deagglomeration → better mass transfer
- Cell destruction → production of soluble chemical oxygen demand (SCOD) and proteins…→ intensification of the anaerobic process
- More biogas and less residue
- 8% to 30% increase in digester performance (VS-degradation up from 42% to 54%)
- Treatment of huge volumetric sludge streams
- Continuous operation at varying sludge properties
- Stability against reactor blocking (sludge impurities)
- Low maintenance
- COD & Color reduction in outlet stream
- Improvement in biodigestion & composting etc.

Awards and Honors to HyCa Technologies Pvt. Ltd.

- Gold medal at DST- Lockheed Martin innovation award for 2012.
- National award for the most innovative water saving product for 2011 from Govt of India/CII at the National Water Conclave, Jaipur.
- FE-EVI Green Technology Honouree from the hands of Hon Dr APJ Abdul Kalam on World Environment Day, 2011.
- Awarded the ET: NOW/Bajaj Hindustan "leap of faith" green entrepreneur of the year for 2012.
- Selected as a portfolio company of New Ventures India(a CII, USAID, UK Foreign & Commonwealth office and World Resources Institute, Washington initiative) 2010
- Showcased at Innovations India organized by IIT Bombay Alumni Association, Pune chapter and in Proto.in in 2010.
- Showcased in the top five start up for the year 2009 in ET NOW.