CAVITATION: A TOOL FOR TREATMENT OF INDUSTRIAL WASTE WATER

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Abstract *:* Many industries release polluted waste water in the surrounding environment which is most toxic to the aquatic life and human health. Cavitation is one of the phenomena which is applied for treatment of waste water for reduction of different hazardous parameters that are released in environment. The aspects of medicinal consumption and release of waste water from textile and dairy industry are increasing day by day which leads to release of different chemicals, by-products and waste into water. This contaminates the natural water, so its effect should be mitigated, for this there are several processes utilize viz. Sonoelectrochemical catalytic oxidation, Acoustic cavitation, advanced oxidation processes. Conspicuously, variety of dyes, chemical dye stuff, pharmaceutical compounds, textile raw materials, etc increases the water polluting parameter. By usage of techniques namely Sonofenton, ultrasound cavitation, Sonolysis, AOPs, Ozonation and Ultrasonic dying the toxicity of chemicals is reduced. To meet the need of better and safer environment cavitation is the good process to degrade the several pollutants that causes pollution. All analysis gives the result that fulfils the required outcome with an effective result.

Index Terms - Cavitation, Advanced Oxidation Processes, Pharmaceuticals, Textile, Dairy wastewater,

1 INTRODUCTION

1.1 CAVITATION

Sonolysis or ultrasound is the prodigy seen in wide number of practical situations i.e. in different equipments. When pressure of liquid falls below the vapour pressure, liquid gets vaporised and converts in vapour, the process continues up to liquid pressure become equal to vapour pressure. Due to this procedure in low pressure region bubbles are formed. These bubbles get collapsed when came into high pressure region. During collision; bubbles have property to damage the surface of material by producing erosion. The rapid and continuous explosion of micro bubbles due to cavitation results in high temperature at water, which causes thermal decomposition of toxic elements in water sample.The very extreme condition generated during cavitation process, water decomposes to create both oxidizing and reducing radicals [1].

Cavitation is defined as the technique of formation, growth and continuous collapse of microbubbles which is occurring in short intervals of time. It is the procedure that produces conditions which is extremely suitable for the degradation or destruction of pollutants. The degradation of pollutants is need current condition that has to be solved efficiently to meet the need of better and safer environment [2].

1.2 TYPES OF CAVITATION

1.2.1 Acoustic Cavitation- Cavitation is occurred by pressure variation in wastewater using ultrasound. Generally, ultrasound of 16- 100 MHz is used of this process. The degradation of contaminants is induced by the introduction of ultrasonic waves. The process is known as sonochemistry as it includes both ultrasonic and chemistry.

1.2.2 Hydrodynamic Cavitation- Cavitation is occurred by pressure variation in wastewater by using the geometry of system to create velocity variation. This phenomenon is usually seen in the orifice meter, venturi meter, etc.

1.2.3 Optic Cavitation- Cavitation is occurred by photons of high frequency light rays that rupture the wastewater solution continuously. It involves the focus of short pulsed lasers in liquid solution, which induces the degradation of contaminants.

1.2.4 Particle Cavitation- The beam of elementary particles is used to produce cavitation [3].

2. WASTEWATER

The treatment of wastewater to reduce the pollution is an important need in modern society to conserve the contents of water. This can be done by using different techniques and traditional methods to abate the contamination of water and get rid of water disposal problem. There are different steps involved to drop the water pollution that includes mechanical purification, aeration and removal of microorganisms to obtain balance of clean water [4]. Pharmaceutical industries comprise of different types of reactants, solvents, solid water during their manufacturing and releases effluent water containing bulk drugs which is hazardous to the environment, human being and mostly to the aquatic life. Moreover, the water used for cleaning and washing purpose in these industries cannot be reused due to strict standards and hence the toxicity is to be reduced for environmental purpose [5].

Studies of Harvey and Loomis have investigated the destruction of the micro bubbles formed due to cavitation was taken under considerable interest since from 1920's. An understanding of cavitation phenomenon has developed in electronic circuitry and transducers from 1945. In 1960 the research focused on understanding the process of ultrasonic interaction between liquid and gas in solution and associated with the shear disruption, heating and free radical production [6]. The amount of dyes disposed into water causes contamination released from industries like textile and paper industries. These dyes sustain in environment for longer period under the conditions of temperature and high stability of life. This is responsible for reduction of solubility of oxygen into water which is the major requirement for photosynthesis for marine life. The dye used in treating effluent textile water is Triphenyl nitrogen that has cationic dye [7].

Combining the technique of ultrasound with Fenton process to reduce the content of Dye called as C.I acid orange 7 from the textile waste water. The oxidising agent like H_2O_2 used to modify the parameters and the properties of waste water to increase its efficiency. The result concluded that the rising content of oxidising agent with intensity of power increases the decolourisation rate [8].

Wastewater contains a number of pollutants and contaminants that includes:

- Plant nutrients (nitrogen, phosphorous, potassium)
- Pathogenic microorganisms (viruses, bacteria, protozoa and helminths)
- Heavy metals (Cadmium, Chromium, Copper, Mercury, Nickel, Lead, Zinc)
- Organic pollutants (polychlorinated biphenyls, polyaromatics hydrocarbons, pesticides, biodegradable organics like BOD, COD)
- Micro-pollutants (medicines, cosmetics, cleaning agents)

These pollutants can cause adverse effects to the environment and eco system. Some of these adverse effects include metal poisoning, irritation and pathogenic infections; eutrophication. Eutrophication causes bio accumulation, bio magnification, toxic material release, and nutrients enrichment effects. To avoid these negative and hazardous impacts there is need to treat the wastewater properly that is releasing into various water bodies [9].

2.1 PHARMACEUTICALWASTEWATER

Numerous kinds of pharmaceutical drugs being used for treatment of human as well as animals are emerging as pollutant in environment. Different type of drugs like Antibiotics, contraceptives, Antiseptics, Antivirals, Antipyretic, Analgesic, etc. are being released to the environment causing pollution rate rise day by day. Some of the pharmaceuticals like Acetaminophen, Codeine, DCF, Aspirin, Caffeine, Amoxicillin, etc. are found in pharmaceutical wastewater that is harmful to the environment [10]. The microbial toxicity, high salt content and high concentration of organic matter are difficult to bio degrade, which are the main components complex pharmaceutical wastewater. In spite of various treatments, the quantity of dissolved organic matters and suspended solids are found in high amount. Different processes applied for treating pharmaceutical wastewater like coagulation, sedimentation, membrane separation, advanced oxidation processes, active carbon adsorption, biological treatment etc. to balance environmental safety [11].

2.1.1 ANALYSIS

Pharmaceutical industries are taken as a rising environmental issues due to their continuous contact and persistence with aquatic environment and hazardous effects on various living species. Treatment of pharmaceutical waste water up to the required standards has always been a challenge due to wide range variety of products produced in pharmaceutical industry [12]. Some of the biologically toxic and refractory pharmaceutical waste water like cephalosporin is tremendous hazardous to the environment. For the degradation of such toxic waste water Sonoelectrochemical catalytic oxidation process is used by using nanocoated electrode. This sonoelectrochemical technology is applied as the advanced treatment method for different industries which releases toxic contents, organic contents, refractories, aromatic and phenolic derivatives, etc. Ultrasound can effectively promote the oxidation activity by producing hydroxyl radicals [13].

The non-steroidal, anti-inflammatory drug like Diclofenac is consumed by human being, whose excretion of 15% from body is remains unchanged, from many pharmaceutical industries it affects the environment and aquatic life too. This toxicity of DCF is decreased by using ultrasound with increasing frequency with different oxidising agents [14]. The Amoxicillin encountered in the pharmaceutical waste water is found toxic and hazardous to the environment. For degradation of such pharmaceutical compound, the aid of ultrasound waves with high frequency is applied along with hydrogen peroxide as an oxidising agent. The highest degradation of Amoxicillin is achieved within 90 min [15].

Across the globe number of pollutants is encountered each and every year, one of them are pharmaceutical pollutants. For the degradation of aspirin in the waste water from pharmaceutical waste water many kinds of advanced oxidation process are discovered. Advanced oxidation with ultrasound is one of the processes which give some benefits compared to the conventional methods. Using probe sonicator system, the degradation of aspirin is carried out for natural and induced conditions are studied and thoroughly concluded that this process can be good option for degrading various pollutants in waste water [16]. The most commonly used drug Ibuprofen that is used to treat fever, pain, injuries and inflammation. By various routes this drug can easily enters into environment. Several researchers reported that partial degradation of IBP is dangerous because after its transformation the products formed are more toxic and hazardous. Using Sonolysis and sono-Fenton process,the degradation of IBP drug is carried out with satisfactory results [17].

The photocatalytic degradation of pharmaceutical compounds using Titanium dioxide is an effective process for the degradation of Azithromycin and Esomeprazole. Up to 60% COD reduction was achieved with utilization of TiO_2Nano particles [18]. For treatment of pharmaceutical waste water various Sonochemical degradation along with various additives are

utilized viz. activated carbon, Fe^{3+}, Hydrogen peroxide, and Potassium dichromate. These additives affect the degradation process thoroughly and give effective outcome [19].

. **Table 1:** Overview of Pharmaceutical wastewater treatment

Sr. No.	Type of WW	Treatment Method	Operating Condition/ Parameters	Results	Comments	Ref.
1	Pharmaceutical WW [EI products, Parwanoo (H.P.), India	Acoustic Cavitation (20 kHz)	Ultrasound wave frequency = 20kHz Time = 2 hrs for settlement of precipitate	COD removal up to 75.53% (75min)	COD degradation increases up to 75min and start decreases after 75min.	[12]
2	Biologically treated cephalosporin pharmaceutical waste water	Sonoelectrochemical catalytic oxidation driven by nano coated electrodes (45kHz)	Ultrasound wave frequency = 45kHz During titanium surface treatment Ti sheet is dipped in 20wt % oxalic acid solution for 1-2 hrs at 96˚C During preparation of traditional anodes Ti sheets was coated with this solution and dried at 120˚C for 10 min. During nanocoated electrode Ti plate is heated at 150˚C for 2 hrs under oxygen atmosphere.	Removal of COD up to 94%	COD degradation increases as the frequency increases upto 45kHz and starts decline after that	[13]
3	Solution containing Diclofenac.	Ultrasonic degradation by using horn sonicator	Power density = (25-100) Substrate concentration =(2.5-80) Initial Solution pH =(3.5-11),	Toxicity of the solution is reduced	Total degradation of toxicity cannot be achieved	[14]
4.	Pharmaceutical waste water containing Amoxicillin	Ultrasound waves equipment with hydrogen peroxide	Time for ultrasound irradiation = 30,60,90. Ultrasound wave frequency = 2.4MHz	70% degradation at 90min	COD cannot be decreased without using oxidising agent.	[15]
5.	Pharmaceutical waste water containing Aspirin	Ultrasound waves with Advance Oxidation Process	Ultrasound frequency used = 20 kHz	Maximum degradation obtain 91.31%	% degradation varies with sonication time Concentration increases % degradation decreases. Sonication time depends on concentration of sample.	[16]
6.	Pharmaceutical wastewater containing Ibuprofen (BASF Corporation)	Sonolysis and sono-Fenton process	Ultrasound frequency = 20, 12,580-862 kHz Power = 180,200,250 Probe diameter = 51,35,40 Applied power = 25,50,100	for Sonolysis process- Pollutant is reduced by addition of n-butanol and acetic acid from 48% to 8% and 40% For sono-Fenton process- TOC reduction was favoured at high frequency and up to 50% of TOC degradation is observed.	pH lowering Did not affect the IBP degradation but it reduces the alkaline value	[17]
7.	Aqueous solution of Esomerprazole and	Photocatalytic Degradation using TiO_2, Sol-gel process.	UV lamp power = 6W protected with quartz jacket Temperature = 400˚C	Esomeprazo is degraded 60% at 0.5 gm/L TiO_2 catalyst within 150 min and degradation of	Degradation of these antibiotics increases when TiO_2 nanoparticles	[18]

	Azithromycin			Azithromycup to 67% in at 1 gm/L TiO_2 catalyst within 150 min at room temperature.	concentration increases	
8.	Pharmaceutical waste water obtained from central ETP plant Chennai, India	Sonochemical degradation along with different additives like Activated carbon, Carbon tetra chloride, H_2O_2 and Potassium dichromate	Sonicator frequency = 30kHz	Alone Sonication after 60min COD reduce up to 41% With addition of Activated carbon 60% COD reduction is obtained With addition of H_2O_2 79% COD reduction obtained With addition of CCl_4 75% COD reduction is obtained With addition of $K_2Cr_2O_7$ 68% COD reduction ids obtained.	Maximum COD reduction is obtained by the addition of Carbon tetra chloride and activated carbon.	[19]

2.2 TEXTILE WASTEWATER

The demand for textile material produced from textile industries and finished products are at high demand due to its high quality. However, the different toxic material released from textile industries particularly dye into the water considerably creates water pollution and degrades the efficiency of environment. The generated contaminants can be reduced by varied range of processes, divided into primary, secondary and tertiary treatments, and the purification of such water depends upon type of matter present in it [20].

Textile industries include variety of components during production, processing and finishing of the product along with the raw materials and different chemicals. Sizing materials like starch, polyvinyl alcohol (PVA), polyacrylates and carboxymethyl cellulose in waste water outlet from the unit, increases the level of BOD, COD and suspended solids. Contaminations present in natural fibres are basically fats, oils, waxes, minerals with plant matter. During the process of scouring the materials used for washing and cleaning purpose are detergents, assisting agents, soaps, defoamer, and lubricants. Wool carbonising, Cotton Merce rising, Dyeing, Bleaching, Printing, Sizing and Desizing releases the effluents that are hazardous to environment to create pollution [21].

2.2.1 ANALYSIS

The textile waste water comprises of a dye namely acid blue 80 (AB80), which can be degraded by using ultrasound cavitation. Where the parameters like pH, volume, amplitude and temperature are indulged [22]. Higher concentration of dye from textile waste water retards the human health along with aquatic life. Many are physio-chemical and biological processes carried out to abate the pollution. Ultimately these processes remove dyes without sludge formation [23].

The waste water from textile industries must be treated to reduce the COD that increases at high amount due to hazardous and numerous dyes. The process of Sonolysis gives the best results to remove dyes from waste water and eventually proves more efficient [24]. Application of varied oxidation processes at optimal conditions like cavitation, Fenton's chemistry, photo catalytic oxidation and ozonation for reducing the particulate matter from waste water. The reagent highlighted is basically hydrogen peroxide to sample for treatment to obtain required parameters useful to mitigate pollution [25].

A new technology emerged to drop down the organic contaminants by using Hydroxide radicals is primarily called as Advanced Oxidation Processes (AOP's). The largest manufactured group of dye is azo dye that creates domestic environment pollution when emitted into water and resist itself for longer time [26]. The Advantages of treating wastewater by ultrasound process increases the efficiency of water content, saves energy, reduces the time required and enhances the environmental conditions. Ultrasound process increases the technique of adsorption and promotes diffusion between molecules and particles of dye in solution by adjusting the fibre structure [27].

The study involves the reduction of the textile dye called as Azo Dye Acid Red B (ARB) by succour of sonication along with presence of pH, anions (Cl^-, NO_3^-, SO_4^{2-})with saturated gas namely argon and oxygen. The conditions applied conspicuously tend to adsorb ARB on oxidising agent MnO_2. Even the particle properties of this agent are studied for efficiency [28]. The waste water containing CI reactive orange 127 and polyvinyl alcohol is treated with Sonofenton and Fenton processes by addition of oxidising agent ferrous ion Fe^{+2} and H_2O_2. Colour content in textile industrial waste water is tremendous and high enough to increase the COD, BOD, acidity salts, suspended solids, heat. These parameters increase their content during further additions of chemicals for textile manufacturing process that widely includes polyvinyl alcohol(PVA) [29]. During combustion of coal, fly ash is been obtained as a by-product that can be initiated to degrade azodye acid orange 7(AO7). This can be achieved through the process of ultrasonic irradiation, eventually this pace proves that there is no

alteration of crystal structure of fly ash. The study of structural dimension along with impact of ultrasound was enhanced by the X-ray diffraction and X-ray energy dispersive analysis [30].

Table 2: Overview of Textile wastewater treatment

Sr. No.	Type Of Waste Water	Treatment methods	Operating conditions	Results	Comments	Reference
1	Acid Blue 80 textile waste water	Ultrasound cavitation	Amplitude = 75% pH = 2.5 Temperature = 30˚C Volume = 200ml	34.94% AB80 degraded.		[22]
2	Dye Waste Water	Ultrasonic Cavitation, Hydrodynamic Cavitation, Cavitation	Frequency = 20 kHz Model ICS = 204 Ultrasonic reactor = 20-40˚C	According to economic considerations cavitation process is effective for textile waste water treatment.	The technique used for lab scale should be evaluated for industrial scale.	[23]
3	Varied Dyes in waste water	Advanced oxidation process for COD removal, Sonolysis	Sonolysis without dipping-90 min pH = 6 with dipping-90 min pH = 6	COD value Obtained 1200-1300 mg/L pH=5.9-6.5	High amount of organic and inorganic matter in waste water indicated through results.	[24]
4	Polluted textile waste water.	Cavitation +H_2O_2 , Photolysis +ZnO, ZrO_2,TiO_2, CeO_2. Fenton's Chemistry, Ozonation.	16 KHz-100MHz alternate cycle of Rarefaction and Compression Multiple Transducer with Frequency 15 KHz-10MHz Photocatalysis at 20KHz for 10-15 min of Acoustic Bath Batch Fenton reactor namely non-pressurised stirred tank reactor pH is maintained up to 6.	Free Radicals formation by using H_2O_2 with the aid of UV Or Ultrasound energy.	Parameters required for operation can be altered by adjusting intensity, Temperature, Pressure Pulse and Frequency. H_2O_2 or Ozone alone won't prove economically beneficial and hence other technical combinations can be applied. Study of individual techniques applied for treating the waste water.	[25]
5.	Acid Orange 7 a textile Azo dye	Sonolysis, Radiolysis and AOP	Frequency = 400 kHz Temp = 296 k	The process of ionizing radiation to treat waste water is still rendered from commercial use.	Pulse radiolysis is deduced to treat the organic substrate	[26]
6.	Textile dying and dyes decolourisation by ultrasound process	Ultrasonic Dying, Sonolysis, Decolourisation	Frequency = 20 kHz to 1 MHz pH = 5.5	To stabilize the harmful compounds from textile wastewater by generating free radicals through ultrasound.		[27]
7.	Azo Dye Acid Orange Red B	Sonochemistry , Decolourisation, Mineralisation	Frequency = 50 kHz, Power = 150 W, Temp = 22˚C, pH = 3.0	The effluent water containing dye comprises of high pH and variations in anion property is more.	Usage of diluted NaOH and HCl is done promptly to maintain pH of contaminated water.	[28]
8	Azodye CI	Fenton, Sono-Fenton	Frequency= 35KHz, Power = 80 W, pH = 3	Fenton removed 89.9% of colour while 91.8% was removed by Sonofenton.	The optimum value of pH which is 3 gives maximum conversion required to reduce harmful effects of pollutants by fenton and sonofenton process.	[29]
9	Acid Orange 7	Ultrasonic	Frequency = 40 kHz,	Combination of flyash		[30]

		irradiations.	pH = 7, Time = 60 min	with ultrasound tends to abate the colour to enhance properties of waste water.		

2.3 DAIRY WASTEWATER

Different sources for generating dairy waste water, is depended on the production of the dairy products. Dairy waste water contains fats, lactose, whey protein, nutrients, inorganic salt phosphates, ammonia and also high concentration of BOD, COD, colour, odour, etc. The disposed waste water to the atmosphere should have low contaminants to mitigate the pollution [31].

Various type of toxic chemicals, organic matter present in dairy waste water so it needs to remove because it effects on environment as well as human life. The different kind of treating processes are used such as coagulation, adsorption, membrane separation, charcoal treatment, High concentration of BOD is not removed directly to atmosphere so breaking up some of components to protect and keep safe environment [32].

2.3.1 DAIRY WASTEWATER ANALYSIS

In Dairy waste water toxic chemicals are not present but high concentration of dissolved organic components such as fats, oils, grease and nutrients are present in it.The dairy waste water treating with different chemicals such as Hydrogen peroxide, Ferrous sulphate heptahydrate, Sulphuric acid and Sodium hydroxide etc. to find the different parameters like pH, Turbidity, TSS, COD and BOD. For this process Cavitation Reactor are used for the degradation. The different range of sonication power is used for the reduction of COD of dairy industry waste water [33]. Ultra sonication and Cavitation processes is used for treated Industrial Dairy Waste Water and also modified physical and chemical properties of different milk constituents (Milk fat and proteins). This processes also study the effects on other milk components. The energy released during both of the processes changes the properties of milk components [34].

Bougrier etc. all that suggest COD released is always related to specific energy and contact time is depends on the temperature. Spectro-photometer model DR/2800, HACH this equipment is used for this process for removing the parameter such as COD, SCOD, TKN, TP etc. Ultrasonic wave irradiation processes cause releasing nutrients from the solid state to soluble form [35]. Ultrasonic membrane hybrid processes is used for dairy wastewater treatment. Hybrid process of Membrane filtration and Ultra sonication for treating industrial dairy waste water. In this processes, Dead-end stirred cell device is used in laboratories scale to find out diffusion coefficients by Fick's law and determination of CMC, Reynolds number, Mass transfer coefficients and concentration on membrane surface [36].

Table 3: Overview of Dairy wastewater treatment

Sr. No.	Type of waste water	Treatment method	Operating conditions	Results	Comments	References
1.	Dairy industry waste water	Acoustic Cavitation. AC+H_2O_2 AC +Fenton Process. AC+Photo Fenton Process.	Storing Capacity = 4c. Frequency = 20kHz. Maximum Power = 800W. Temperature = 28±3°c.	pH = 6.5. Turbidity = 12 NTU Hardness = 640ppm. COD = 900+50mg/L BOD = 580 mg/L TDS = 1922 mg/L TSS = 651mg	COD contain is decreases in addition of different chemicals.	[33]
2.	Dairy Waste Water	Ultra sonication, Acoustic cavitation and Hydrodynamic Cavitation.	Low frequency = 20 & 500kHz High frequency = Higher than 100. Pressure = Higher than 1000atm. Temperature = 70 to 75°C		Reduction of particle size up to nanoscale dimensions. Advantages of Ultra sonication and Cavitation.	[34]
3.	Dairy waste – Activated Sludge	Ultrasonic wave Irradiation	Spectro-photometer model DR/2800, HACH. Temperature =1 2°c. Contact time = 480s. Output Power = 500W. Diameter = 6mm.	Released nutrients from the solid state to soluble form.	More than 96% of COD is insoluble form converted to soluble form.i.e.640% More than 68% of TKN is in	[35]

					insoluble form converted to soluble form.[170% foundTKN] More than 92% of TP is in insoluble form converted to soluble form[116% found TP]	
4.	Dairy waste water	Ultrasound membrane hybrid process.	Power = 100 Watt Frequency = 30 kHz Temperature = 50°c. Pressure = 0.1 Mpa	CMC=2.38g dm-3 at 50° C. Ultra sonication retentions incresesd from 53.1 to 65.4% and to 74.7%	Determine the Diffusion coefficients by Fick's law and calculated Reynolds no, CMC.	[36]

3. CONCLUSION

The presence of Pharmaceuticals, Drug compounds, Dyes, Toxic chemicals, Organic compounds and many other pollutants in the wastewater of Pharmaceutical, Textile and Dairy industries is a huge challenge for the living organisms in environment. For degradation of such toxic and hazardous compounds in the wastewater to meet the need of safe environment can done by using ultrasound as an effective option with satisfactory results. The process is carried along with various oxidising reagents, using electro chemistry, photo catalysis and other chemicals to increase the percentage degradation. Use of ultrasound is eco-friendly option to degrade pollutants and reduce the pollution. It might be a best option for treating the industrial wastewater.

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NOMENCLATURE:

Abbreviations	Full form
AC	Acoustic Cavitation
HC	Hydrodynamic Cavitation
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
TOC	Total Organic Compound
TSS	Total Suspended Solids
AOP	Advanced Oxidation Processes
C.I	Colour Index
IBP	Ibuprofen
AB80	Azo Dye Acid Blue 80
ARB	Azo Dye Acid Red B
AO7	Azo Dye Acid Orange 7
PVA	Poly Vinyl Alcohol
DCF	Diclofenac
SCOD	Soluble Chemical Oxygen Demand
TKN	Total Kjeldahl Nitrogen
TP	Total Phosphorous
CMC	Critical Micelle Concentration
NTU	Nephelometric Turbidity unit
BASF	Badische Anilin und Soda Fabrik
UV	Ultra Violet
EI	Esico International