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Article

Plasma Based Water Purifier:Design And Testing Of Prototype with Different samples of water

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Abstract: The objective of the prototype is to eliminate the polluting contamination of water sources, due to the leak of industrial waste without any kind of treatment, mainly generated by the industries and home sector. In this project, a prototype of water purification by plasma technology has been designed. The prototype will convert contaminated water into the plasma stream and eliminate the pathogens from the water by exposing it to ultraviolet radiation and plasma sterilisation. The polluted water will be accelerated at high speed using a water pump in order to convert it into a liquid-gas mixture for ease plasma generation. This process will be achieved when the electric supply from a source of alternating current (AC) is applied to the water by means of high voltage electrodes. After which, the mixture slows down to return into liquid form and the clean water is obtained. The whole process takes place without significantly raising the temperature also knows as non-thermal plasma. The device also has an automatic flow and pressure control system. Finally, a short feasibility study has been conducted on the water samples collected and report obtained from Chennai Metropolitan Water Supply and Sewage boards are reported. It has been concluded that this new plasma-based water treatment system will be more efficient and cheaper than the current wastewater treatment techniques and can be used in the future as the replacement of current secondary and tertiary treatments of industrial wastewater.

Keywords: Plasma generation, non-thermal Plasma, pulsating DC power, Ozone, cost-improvement

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1. Introduction

Nowadays, demand on the environment quality has rapidly increased. It is considered sharply watched and an important subject is water environment, since its harmlessness for the human race and nature in general. The wastewater releasing from chemical industries and households most often contain harmful compounds. These compounds can be dangerous or even toxic for the Earths environment, and they can even cause several problems to the human race. Therefore it is very important to purely observe these compounds in water, and also to remove them from this environment. The best way is to prevent the contamination in water by saying not to use harmful compounds in the households and industry. But this not possible at all so, it is important to know how water can be treated to become harmless[1]. For the water treatment, different methods of water treatment have been used for centuries and developed. These treatment methods are divided into four different methods: physical, chemical and biological.

Biological methods are the wider one for water treatment techniques. The main advantage is low operative cost and most widely used by municipals and industries. The main disadvantage is not a very efficient process for removal of harmful pollutant. Moreover, the process of biological degradation of pollutants is significantly slower than other processes[6]. Physical methods are based on a pure

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mechanical separation in which waste products from water by a particular supporting system like charcoal and filter paper. The advantage of this process is there is no chemical involved. On the other hand, physical methods are not sufficient for the removal of most of the hazardous compounds, especially on the organic basic compound. In conflict to the physical method, chemical oxidation processes are more often used for the treatment of water which is contaminated by organic compounds. The most common oxidants are chlorine dioxide, chlorine, ozone, and potassium permanganate. But this reagent forms the hazardous by-products[4]. So this problem is solved by the ozonisation process which is efficient but more costly in comparison.

Plasma in the liquid can be generated by the different electrode configuration in the coaxial reactor design, with the A/C voltage is applied for the discharge ignition to take place. This discharge in the liquid will initiate the various chemical and physical reaction which is used for the purification of water. The electric discharge will initiate some of the physical processes like a strong electric field, UV radiation and formation of shockwaves. On the other side, chemically reaction such as radicals, high energetic electrons, ions and molecules with high oxidation potential is the most desirable chemical process[1]. Based on the above process This could be used for the treatment of the wastewater from the factory without the use of any additional chemical. Through this process, not only the organic pollutant but also the inorganic pollutant can be treated. Another use of plasma is in the plasma sterilisation (killing microorganism) and surface treatment(Hospital waste).

2. Plasma in Liquid

An application of high electric energy into the system leads the intensive movement of the particle which collides with each other and forms the change ions. Finally, plasma is generated due to this highly charged particle. In general, the plasma which is generated in the gas or liquid phase leads to the generation of the non-thermal plasma, which has been used for the plasma-based water purifier[3].

Plasma generation dependent on the environment in which the plasma is ignited. Plasma in the liquid depends on the three main factor:

- Higher is the density of the medium induces the high collision frequency and low charge particle mobility.
- High polarity and dielectric strength of water molecules which lead to the creation of dipole momentum in the applied electric field and inhomogeneous areas in the vicinity of an electrode surface.
- Discharge creation in the liquid phase is a presence of ions and their different mobility in a solution.

Higher is the density of the medium induces the high collision frequency and low charge particle mobility. high polarity and dielectric strength of water molecules which lead to the creation of dipole momentum in the applied electric field and in-homogeneous areas in the vicinity of an electrode surface Discharge creation in the liquid phase is a presence of ions and their different mobility in a solution. From the above facts, we can conclude that for the plasma to get generated by amplification of the applied electric field in order to achieve high electric intensity sufficient for the discharge breakdown. For the breakdown of liquids appears if the electric intensity of 1 MV/cm is reached, which is likely not possible. But we know In the gas phase, the required electric intensity is about 30 kV/cm at atmospheric pressure. By using the above gas phase fact now by using the high-pressure pump and nozzle liquid-gas mixture is created and then the voltage is applied. From their plasma is generated[1].

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3. Prototype Design

3.1. Process Involved

A reactor model was designed. The main advantage of the prototype, since it produces the non-thermal plasma which will not increase the temperature of the water, which intestinally neglect the use of any cooling system. The device featured a pump and a nozzle which accelerates the pollutant water to high speed to convert it into a liquid-gas mixture in order to transform it into plasma. The electrical discharge is applied to the water by mode of two sharp copper electrodes from a pulsating DC power supply. Later the mixture is decelerated and returns it into the liquid state to obtain clean water, without a temperature rise[3].

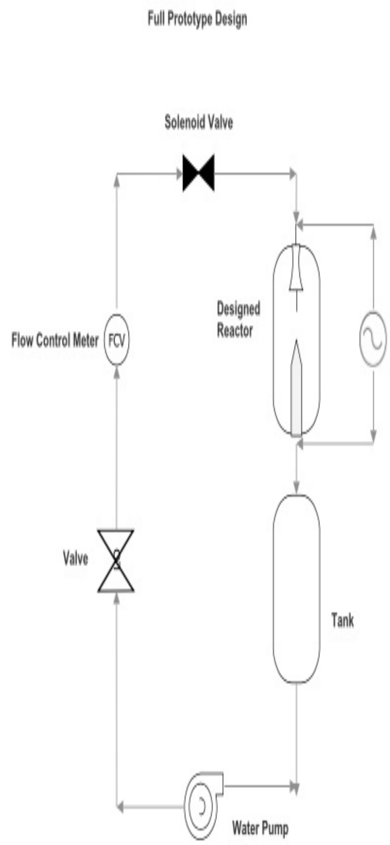

Figure 1. Full Schematics Diagram Of Water Purifier

3.2. Main Design Parameter

- **Reactor**: Coaxial geometry with the copper electrode, 22 cm in length and diameter of 9 cm, Hollowed pyrex tube.
- **Power Supply**: output A/C, 34 Kv,10 kHz Input D/C, 24v (Laptop charger)
- **Nozzle**: 20 l/min @70psi
- **Pump**: 1 hp, single-phase
- **Tank**: 50 liters, fiberglass material
- **Others**:solenoid valve

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3.3. High voltage sources

The voltage source used for the discharge generation is the Non-pulsating DC voltage with high frequency about 25KHZ. The simplified scheme of the DC HV source is shown in Figure. By a simple setup, it is possible to generate 30KV from a flyback transformer.

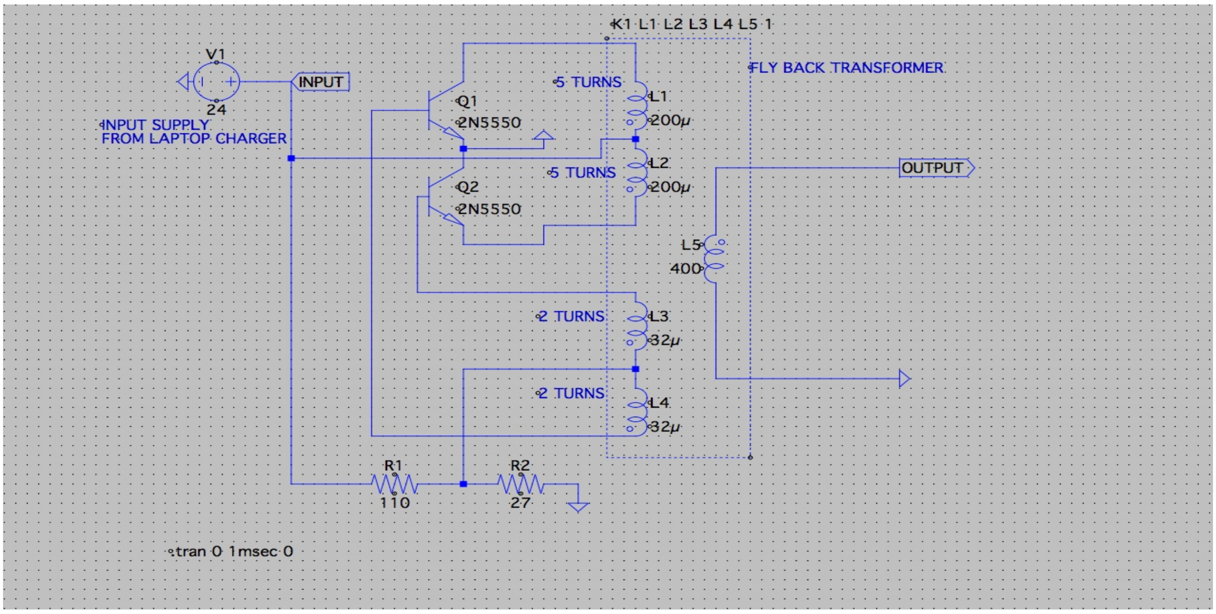

Figure 2. Simplified scheme of DC HV source connected to the discharge reactor

The HF high voltage source was also specially constructed to supply the plasma devices by high-frequency power. It consists of DC sources of 24 Volt for the simplicity laptop charger is enough, Which is coupled with the flyback transformer driver circuit and at the end of the flyback transformer, 30 kV is obtained. The efficiency of the source is approximately 80 Percent.

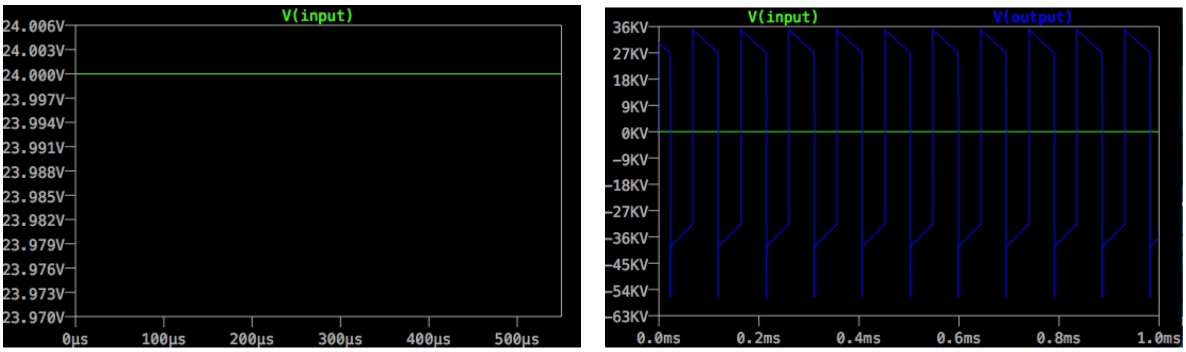

Figure 3. Typical Input And Output Voltage Simulation in LTspice

3.4. Experimental Reactor Device

The first prototype of the discharge reactor was constructed in our laboratory and it has been used in experiments. Discharge reactor used for the plasma generation in water solution has some basic geometry base called as coaxial configuration. The reactor is divided by the dielectric barrier (water) between the two electrode one with the high voltage and other grounded. The main body of the reactor is made of Pyrex and it can fill with 500 ml of water. The attachment of a nozzle made

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perfect to create the liquid-gas mixture. Majorly give an aggressive advantage over other reactors based on parallel plate's configuration.

Figure 4. Photograph of the simple discharge reactor, which is used mainly for plasma diagnostics

4. Water Sample solutions

After the design of the prototype, work is to check the various water solution interaction with water. For this purpose, tap water is used to support a required conductivity. In some experiments, organic and dye are dissolved. The solution is pumped into the reactor. Subsequently, an appropriate high voltage source is connected to the plasma reactor.
Generally, the experimental solutions consist of following item combinations:
a) water + organic dye
b) water + humic acids.

4.1. Organic Dye (Beetroot Dye Extract)

In order to study the decomposition of the dye in water by the plasma, an organic dye selected is BeetrootExtract. The advantages of the dye are that decomposition rate is proportional to the decoration and this effect is visible to the eyes. Here the only problem comes up with the formation of by-products during the dye interaction with plasma.

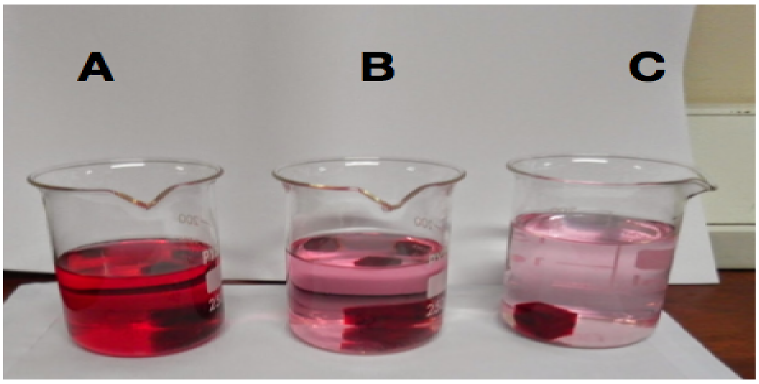

Figure 5. Dye Extracted from Beetroot

4.2. Humic Acid

The organic compound is the humic acid which is organic matter distributed in terrestrial soil, natural water, and sediment. Humic substances are formed by the microbial degradation of dead plant matter, such as lignin and charcoal. The mixture consists of a commercial product HUMIN-P 775

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dissolved in deionised water for the testing. The concentration of humic acids in this solution is 1.9 mg/L.

5. Observation

Ignition of plasma in water solutions requires a configuration of the plasma reactor as well as proper experimental conditions. Both the device parameters and water properties are important in the process of the discharge creation. This part of work deals mainly with the DC non-pulsed voltage. The important processes such are bubble formation and electrolysis is detected as well. According to the breakdown theories in water, the discharge ignition can start in bubbles of evaporated liquid or by the direct ionisation of water molecules. Due to a high potential gradient between the outer and inner bubble surface, the ionisation of water vapour occurs and thus the discharge is ignited.

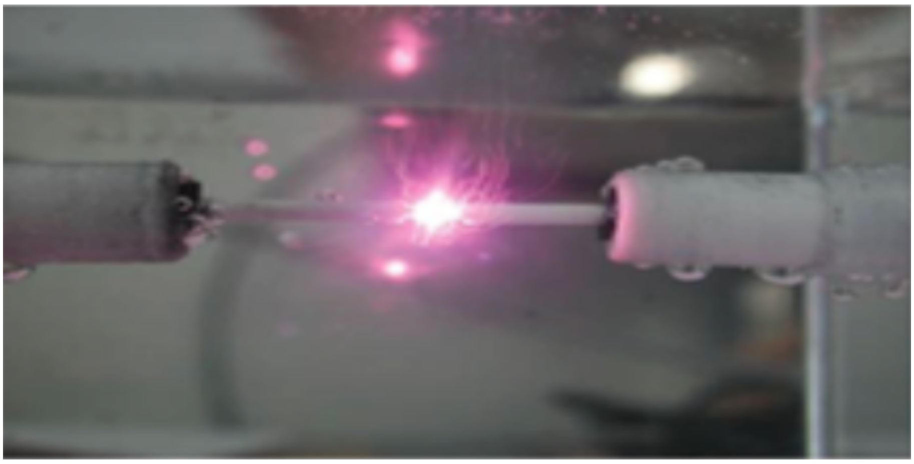

Figure 6. Plasma streamers

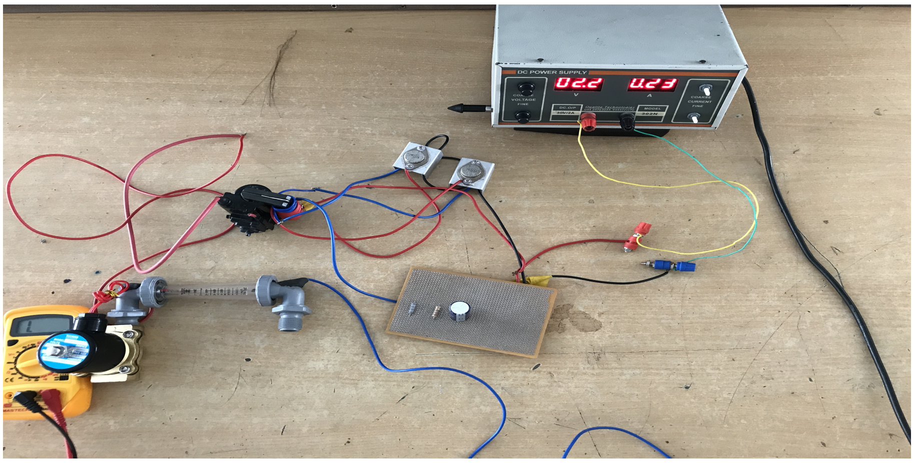

Figure 7. Overall Rough Experimental Setup

The following process can be seen in the plasma in water:
1. Plasma Streamers
2. UV Radiation
3. Ozone
4. Plasma Sterilization

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6. Result

A short feasibility study has been conducted on the water samples collected and report obtained from Chennai Metropolitan Water Supply and Sewage board are reported. It has been concluded that this new plasma-based water treatment system will be more efficient and cheaper than the current wastewater treatment techniques.All the experiment common solution was found, as the pH is maintained with in the limit.After plasma treatment water has become more suitable for drinking.

Table 1. Experiment Results of Normal Water Before And Plasma Treatment.

Chennai Metropolitan Water Supply and Sewage board				
Physical and chemical examination	Tap Water Before Plasma Discharge	Tap Water After Plasma Discharge	IS:10500-2012 Acceptable limits	IS:10500-2012 Permissable limit
Colour	Colourless And Clear	Colourless And Clear	Agreeable	Agreeable
Odour	NIL	NIL		
Turbidity	0.1	0.1	1	10
Total Dissolved Solids At 105 C (mg/l)	1140	475	500	2000
Calcium (As Ca) (Mg/L)	124	32	75	200
Magnesium (As Mg) (mg/L)	58	17	30	100
Total Hardness (As CACO3) (Mg/L)	550	148	200	600
Chlorides (As Cl) (Mg/L)	260	144	250	1000
Ammoniacal Nitrogen (As N) (Mg/L)	0.040	0.040	-	-
Oxygen Absorbed (Tidy's 4 hour Test) (Mg/L)	0.75	0.45	-	-
Hydrogen Ion Concentration (pH)	7.2	6.5	6.5 to 8.5	6.5 to 8.5
Fluorides (As F) (Mg/L)	0.10	0.10	1.0	1.5

Table 2. Experiment Results of Water+Dye Before And Plasma Treatment.

Chennai Metropolitan Water Supply and Sewage board				
Physical and chemical examination	Dye+Water Before Plasma Discharge	Dye+Water After Plasma Discharge	IS:10500-2012 Acceptable limits	IS:10500-2012 Permissable limit
Colour	Reddish	Colourless and Clear	Agreeable	Agreeable
Odour	Earthy	NIL		
Turbidity	69	0.5	1	10
Total Dissolved Solids At 105 C (mg/l)	975	975	500	2000
Calcium (As Ca) (Mg/L)	92	96	75	200
Magnesium (As Mg) (mg/L)	41	70	30	100
Total Hardness (As CACO3) (Mg/L)	400	530	200	600
Chlorides (As Cl) (Mg/L)	330	200	250	1000
Ammoniacal Nitrogen (As N) (Mg/L)	0.090	0.030	-	-
Oxygen Absorbed (Tidy's 4 hour Test) (Mg/L)	3.43	0.24	-	-
Hydrogen Ion Concentration (pH)	8.6	7.5	6.5 to 8.5	6.5 to 8.5
Fluorides (As F) (Mg/L)	0.10	0.10	1.0	1.5

Table 3. Experiment Results of Water+Humic acid Before And Plasma Treatment..

Chennai Metropolitan Water Supply and Sewage board				
Physical and chemical examination	Humic acid + Water Before Plasma Discharge	Humic acid + Water After Plasma Discharge	IS:10500-2012 Acceptable limits	IS:10500-2012 Permissable limit
Colour	Yellowish	Colourless and Clear	Agreeable	Agreeable
Odour	Earthy	NIL		
Turbidity	35	0.4	1	10
Total Dissolved Solids At 105 C (mg/l)	890	1220	500	2000
Calcium (As Ca) (Mg/L)	72	220	75	200
Magnesium (As Mg) (mg/L)	53	56	30	100
Total Hardness (As CACO3) (Mg/L)	400	780	200	600
Chlorides (As Cl) (Mg/L)	320	430	250	1000
Ammoniacal Nitrogen (As N) (Mg/L)	0.048	0.030	-	-
Oxygen Absorbed (Tidy's 4 hour Test) (Mg/L)	2.92	0.30	-	-
Hydrogen Ion Concentration (pH)	8.6	7.5	6.5 to 8.5	6.5 to 8.5
Fluorides (As F) (Mg/L)	0.10	0.10	1.0	1.5

7. Conclusion

As mentioned, the human must treat the wastewater in order to ensure the protection of the environment. It is possible that, due to the high cost and maintenance of traditional treatment plants, people find it difficult to properly treat the contaminated waters. Although experimental data will only be definitive the device is built and tested, it is intended that with the proposed device, cost, maintenance and space could decrease significantly. Which could lead industries especially from developing countries to reconsider discharge untreated sewage. Finally, the ideal state is to offer a whole new cost-improvement, effective, efficient and innovative concept on wastewater plants, for example, by using plasma which could segregate and retain certain organic/inorganic components from the water, and then, eliminate biodegradable organic matter (like microorganisms, bacteria, virus, etc.) by means of the proposed reactor.

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