Plasma Technology Research and Its Applications: developing in the Faculty of Science and Mathematics Diponegoro University

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ABSTRACT

Researchs on the application of plasma technology in the areas of environment, health, food, agriculture have been conducted in the Laboratory of Atomic and Nuclear Physics Division of Plasma Technology in the Faculty of Science and Mathematics, University of Diponegoro. This paper reported research results on plasma technology and its applications in these fields that have been carried out in the recent years. Plasma for environmental applications can reduce gas emissions released by motorcycle and vehicle exhausts. This technology can reduce significantly emissions of SOx, COx, and NOx. Non-polluted plasma muffler prototype adaptation has been done in four wheels and more vehicles. Pilot scale improvement has done by integrating reduction system into vehicle muffler from it previous position outside the muffler. High voltage that used to develop plasma condition comes from 12 V 34 A accumulator which connected with electronic equipment and able to develop voltage up to 20kV. Exhaust gases reduction Ability has done by varying engine rotation. Plasma muffler appearance in vehicle doesn't change outside dimension of its original muffler and it reactor placement in muffler has a function to change resonator chamber function and make this muffler still fulfill muffler standardization with more performance in reducing exhaust gases (COx, NOx, HC). Optimal reduction level made at 2200 rpm for COx is 88.52%, for CO is 88.93%, for HC is 97.34% and for NOx at 4800 rpm is 76.19%. In the health sector the ability to plasma technology to kill bacteria is also reported. Bacteria decontamination by using glow discharge corona non-thermal atmospheric plasma has been developed and tested. Plasma was generated in a reactor plasma positive corona with electrodes geometry multi point to plan configuration electrodes. This plasma has been generated in air with threshold corona voltage was 3.0 kV inter electrodes distance was 0.4 cm and current was 1.5 mA. Sterilization test has been done by bacteria Escherichia coli decontamination. In agriculture we use plasma technology to enrich the nitrogen in the plant of corn, mustard and mangroves. Acceleration of the growth of mangroves, we found that mangroves can be reduced early growth to have two leaves that usually takes 60 days to 28 days or save time approximately equal to 100%. More resent of our research on ozone production by using silent plasma or Dielectric Barrier Discharge Plasma (DBDP) and implemented for microbial inactivation in rice has been done. We realized the Ozone Technology for Rice Storage System (OTRISS)

Keywords: Plasma, environment, health, food, agriculture, ozone, rice

1. INTRODUCTION

Research on the application of plasma, we started experiment for exhaust emissions began in the midle of 1998, by first making equipment prototype particle separator (Electrostatics Precipitator). At the end of 1998, only started making gas removal from exhaust system when it is used as an industrial gas CO2 as gas simulations. This study is quite long about more than one year with funding (self-funding). For this initial study are still using gas reduction system additive Ar, NH3 and water vapor. Research conducted between 1999 until early 2003, another gas emissions vary between pure CO2 from industrial, NO2 from burning coal and HC and COx from the motor of the machine of 2 tags motorcycle. The entire study was still static gas in the plasma reactor. In other words, put gas emissions inside the reactor, then the reactor was closed and done with the reduction of plasma a few minutes. In addition it was also added argon, ammonia (NH3) and H2O in the form of steam as a gas additive into the reactor [1].

The road map of innovation and development in collaboration with industry for commercialization forwarded by creating a plasma reactor system modified many times. From reactor system generation-1 through seventh generation, in midle of 2004, where negotiations with industry has been done. Until the reactor system 6th generation, high-voltage source used is dependent on the electrical voltage source from State Electricity Company (PLN). To get into the motor vehicle stages that must be passed is continuously flowing gas emissions from
vehicles through the reactor. Removal of emission gas by plasma technology in this case, must be plasma generated by a generator that can be moved (mobile generator) and placed in a car or motorcycle. The voltage at the motor or the car battery is 12 volts voltage source. However, to turn on motorcycles and cars there are on the spark plug ignition system with very high output voltage. It can be modified to generate the plasma. What additive Ar gas, NH3 and H2O vapor form? Additive gas is only used until the 3rd generation reactors. With the principle that fuel has actually contain the elements N, C, H, O, S, P then of these elements scientifically possible radical reactions. Additive gas so no longer need to be used. Reduction system can be simplification, more compact and do not need to use the gas in the tube is heavy and dangerous. Phase innovation is very convincing when the research team managed to raise plasma generator car ignition termodefikasi we call the generator moving (mobile generator), in March 2004. The combination of the use of reactor - generation mobile generators 7 and more convinced of this research team that exhaust plasma tech is not an impossible. Her birth was a matter of the type exhaust time with patience and persistence and capital funding. This combination also get high enough reduction results for various gases emissions such as COx, NOx, SOx and HC of the engine 4 tags with gasoline and diesel fuel as well as coming out of the exhaust gases continue mangalir without the need for a certain residence time in the reactor. Research and development innovation begins with its own funds, and then for 3 years from the Higher Education received funds through competitive grants program (HB XI). The research team were 3 lecturer involved with student research assistants were 9 students and 1 alumni [1]. There are other studies of plasma applications research has been done by a team of radiation applications and materials engineering. The last few years the application of cold plasma (non-thermic) has been utilized for a variety of fields including industrial world. The Study Center for Radiation Applications and Materials Engineering (SCERAMEG) in the Research Institute of Diponegoro University in collaboration with the Department of Physics, University of Diponegoro was doing some research on the application of plasma, among others, in the field of agriculture, biology, environment, health, and engineering materials. In the health sector, the most prominent application of plasma is to kill germs, bacteria. The ability of free radicals generated by the gases in the plasma state can be used to kill germs as the basic techniques of sterilization. This research on the world level can also be enhanced. Diponegoro University research groups have tried plasma plasma for sterilization capability but require further refinement [2]. The ozone generator with Dielectric Barrier Discharge Plasma Technology (DBDPT) with Spiral-cylinder configuration has been developed. DBDP Reactor was constructed with spiral wire and cylinder has been reported by Nur et. al [3]. Plasma condition has been generated by using AC high voltage. Ozone has been produced by this technology with oxygen and dry air as sources for ozone generating. In this research we found that the concentration of ozone produced increases with increasing voltage with a time constant. This concentration also increases with increasing time in certain applied voltage. Ozone concentration was higher than the concentration of dissolved ozone in water. Dissolved ozone in water was only 10 % of ozone produced and only 7 % for dry air as source. Oxygen as source of ozone was better than dry air; both for ozone produced and dissolved ozone in water [3].

Other applications in the health field is the use of radio-frequency plasma generation through (RF) for physiotherapy. In the field of biology and agriculture in the broad sense, the application contained in the application of plasma ions and plasma radicals mainly N2+, N+ and N* radicals to accelerate the growth of dormant plants (plants difficult to grow) [5].

### 2. METHODS

Applications in the field of environment: plasma generated by corona discharge plasma configuration with field points and field wire configuration. The high voltage used is high voltage DC. Plasma generator has been able to put in motorcycle and automobile exhaust. Gas emissions out of the exhaust were measured with a gas analyzer [1]. For agriculture application especially on acceleration of mangrove growth, we used free air taht contains 78 % nitrogen molecules. When the plasma generated in the free air or nitrogen molecules will be ionized to form free radicals, N2+ ions were implanted into candidate of mangrove roots that occur supporting nutrients effectively and will eventually accelerate mangrove growth rate. The key role of nitrogen in the growth process chain trees in rural areas of research has been conducted in China [5]. Our very resent work in the laboratory, we used ozone to assurance the quality of rice [7]. Figure 1 shows experimental setup of this work. Ozone was produced by Dielectric Barier Discharge Plasma (DBDP) with spiral–cylinder (S-C) reactor and multi point-plane (MP-P) reactor.
DBDP was generated by AC voltage of 25 kV and frequency of 23 k Hz. The electrical parameters of the DBDP are determined using a high voltage divider (HV Probe DC max Voltage DC 40 kV; AC 28 kV code number EC 1010, En G1010). Their signals are detected by oscilloscope (Osilloscope GOS-653,50 MHz). Current has been measured by Multimeter (Sunwa TRXn 360). Photograph were taken by CCD Camera (Creative, DV Cam 525D). The output ozone concentration from two types of generators was measured using an ozone monitor (Quant Ozone “2”). The measurements were carried out at different applied voltage, different diameter of cylinder electrode/pyrex tubes.

3. RESULT AND DISCUSSION

3.1 Plasma for Environmental Application

Before reduction, vehicle exhaust inserted into the plasma reactor to measure pollutant concentrations of CO₂, CO and HC by using gas analyzer. The concentration of CO₂, CO and HC were measured before this reduction was a reference in comparing the rate of reduction of CO₂, CO and HC after removal by plasma reactor. In the corona glow discharge plasma conditions, ionization occurs causing a chain dissociation of CO₂, CO and HC as well as other gases contained in exhaust gases such as water vapor (H₂O) and HC become ions, electron, and radicals energetic. The process of formation of radicals by electron multiplication is called the initiation phase of the reaction mechanism of free radicals.

![Figure 2: Graph reduction of plasma muffler reactor of motocycle with variation of gear levels and machine rotation of 3200 rpm](image-url)
Next on stage propagation in the mechanism of free radical reactions, energetic radicals are unstable molecules will react with exhaust gas molecules present in the plasma reactor prototype resulting in dissociation -new dissociation of the gas molecules. According to Chang (1991), dissociation of CO\textsubscript{2} to produce CO, C*, and O*, dissociation of CO will produce C* and O*, while the dissociation of water vapor (H\textsubscript{2}O) to produce H, and OH*[1]. The mechanism of free radical reactions ended when radicals generated from the dissociation process react to form new compounds are stable so that the concentration of CO\textsubscript{2} and CO in the exhaust gas is reduced. Ability to reduce the generation of corona discharge plasma reactor mounted on a motorcycle muffler 110 cc can be seen in figure 2.

Reduction in the 4th of gear level with variations of machine rotation showed in the figure 2. We found that the maximum of reduction at machine rotation of 4000 rpm and minimum for 7000 rpm. In these conditions, the best reduction was CO in the amount of 92.86%. The best difference is caused by the reduction of the likelihood of collisions with electrons to reduce it takes more energy to transfer electrons. Molecular dissociation effect of photons emitted from the corona discharge. Corona discharge emits photons of events deexcitation. This study shows that plasma non-thermic appliances can reduce gas emission 4-tags 120 cc motorcycle. At a certain rpm and gear rotation will result in different efficiencies at each gas, but the composition of the reduction of CO is much more efficient than CO\textsubscript{2} and HC, it is because of CO is more electronegative than CO\textsubscript{2}. Some of the content of aromatics formed in this study it is known through the aroma arising during corona discharge occurs. It can be caused of the conversion of HC in the collision of electrons or other chemical reactions.

![Figure 3: Graph reduction of plasma muffler reactor of motocycle with variation of rpm levels for CO, CO\textsubscript{2} and HC](image)

Finally we can say that plasma for environmental applications can reduce gas emissions released by motorcycle and vehicle exhausts. This technology can reduce significantly emissions of SOx, COx, and NOx. Non-polluted plasma muffler prototype adaptation has done in four wheels and more vehicles. Pilot scale improvement has been done by integrating reduction system into vehicle muffler from it previous position outside the muffler. High voltage that used to develop plasma condition comes from 12 V 34 A accumulator which connected with electronic equipments and able to develop voltage up to 20kV. Exhaust gases reduction Ability has done by varying engine rotation. Plasma muffler appearance in vehicle doesn’t change outside dimension of its original muffler and it reactor placement in muffler has a function to change resonator chamber function and make this muffler still fulfill muffler standardization with more performance in reducing exhaust gases (COx, NOx, HC). Optimal reduction level made at 2200 rpm for COx is 88,52%, for CO is 88,93%, for HC is 97,34% and for NOx at 4800rpm is 76,19%

### 3.3 Plasma for Agriculture

**Plasma Technology for Growth Stimulation of Seeds (PTGSS)** (especially for Mangrove) has been implemented on field scale at Center for Mangrove Seeds in Desa Kaliuntu Kecamatan Pasar Banggi, Kabupaten Rembang. The goals of activities for Implementation of Applicable Integrated Technology such as: application of derivative technology for growth stimulation of mangrove seeds base on Plasma Technology on agro-industrial scale of mangrove. Other goal is how to find mangrove seed with rapid growth quality, both for pre plantation and after
plantation. Moreover, these activities has goal how to increase knowledge mangrove farmer community about the integrated “wanamina” concept.

Figure 4: Picture of the use of PTGS in mangrove Rhizophore with treatment time variations

They are as salt farmer, as mangrove farmer and the same time as fishery. The goals of TTT program have been curried out by conducting several activities such as: to offer and introduce how to use Plasma Technology for Growth Stimulation of Seeds (PTGSS) to the farmer mangrove community, represent by Mangrove Farmer Group. This equipment will become community asset. Conducting workshop about how to plant diversification of mangrove species. And also, conducting workshop on concept and practical aspect mangrove plantation base on “Wanamina” concept. Implementation of Plasma Technology for Growth Stimulation (PTGS) for mangrove on field scale has been applied successfully with growth acceleration was 43% [5].

This result indicated that PTGS can reduce time for pre plantation of mangrove until 2.4 months. That’s mean, the farmer can reduce cost pre plantation of mangrove and increase 43 % of the benefit for the farmer if we compare with before using PTGS. Moreover, resurveying the results of plantation mangrove base on Wanamina concept, we found that this concept enriched and enhanced macrobenthos, plants species, animal species and plankton species at Kaliuntu territorial waters, Pasar Bangi. Implementation of PTGS augmented self confidence of mangrove farmer community due to using new technology for products defrentiation. Fathermore, it is not less important is the success of the field trials of Plasma Technology for Growth Stimulation (PTGS) in the field. Results of the field trials gave us particular success for Plasma Application in the Comunity Services by Diponegoro University [5].

3.2 Plasma Application for Rice Storage

We used plasma technology to produced ozone that has been used for microorganism disinfectant. Ozone generator was a combination of Dielectric Barrier Discharge Plasma reactor (DBDP) with a spiral configuration of copper and copper cylinder with dielectric pyrex pipes (diameter of 3 cm and a length of 15 cm for research on rice with small and medium capacity). To comply with the requirements of adaptation to rice storage containers, using one generator unit 7 reactor DBDP.

3.2.1. Inactivation of Bacteria

Bacteria decontamination by using glow discharge corona non-thermal atmospheric plasma has been developed and tested. Plasma was generated in a reactor plasma positive corona with electrodes geometry multi point to plan configuration electrodes. This plasma has been generated in air with threshold corona voltage was 3.0 kV inter electrodes distance was 0.4 cm and current was 1.5 mA. Sterilitzation test has been done by bacteria Escherichia coli decontamination. These bacteria were planted in EA (Merck) medium glass cup with diameter of 10 cm. Corona glow discharge plasma decreased number of microorganism coloni (CFU/ml) in the surface of cup. The result shown that this system killed 96.8 % of bacteria population after 100 second of plasma radiation. The energy consumtion of plasma decontamination system was smaller than energy consumtion of UV decontamination [2]. Total bacteria in rice determined by using Total Plate Count (SPC) with medium Plate Count Agar (PCA). In figure 5, we found that the influence of ozone on total bacteria that contaminate rice showed a negative correlation. Bacterial growth is inversely related to ozone exposure time. The average number of bacteria decreased 0.69 log CFU/g every 30 minutes for increasing treatment.
This situation was due to the number of bacteria contaminants were not able to survive until the breeding process. Thus leading to slower population growth. Effect of ozone on total bacterial is presented in the figure 6. The curve above shows, the optimum point decrease bacteria occurred in 90 minutes treatment. The number of bacteria dropped 2.98 log CFU/g of initial state (5.11 log CFU/gr). Growth of bacteria in 90 minutes, reaching only 2.13 log CFU/gr indicate that most of the bacteria are dead before the breeding process (in vitro incubator) done. Remaining bacteria after 90 min treatment was 41.6% of the total bacteria before treatment, or can be said to be 58.4% of bacteria die before breeding. The most significant decrease occurred curve between 0 to 30 minutes of treatment, where the number of bacteria dropped 1.39 log CFU/gr compared to the transition time of 30-60 minutes (reduced by 0.69 log CFU/gr), 60-90 (reduced by 0.90 log CFU/gr), and 90-120 (which accrue 12.23 log CFU / g). The curve in Figure 6 above showed an increase in the bacterial population of 120 minutes in which the population of bacteria that grows up 12.23 log CFU/gr compared to 90 minutes. This case has also been reported by some researchers such as Voidarou et al., [8, 9, 10, 11] and later was named the biphasic death curve.

In this results, determination number of fungi colonies shows, the total number of fungi on average are on the order of 10^1, both before treatment and after treatment. Log CFU values indicate that a relatively small number of fungi that contaminate the rice. According to the calculation, total colony of fungi decreased on average 0.074 log CFU/gr each 30 minutes increasing of treatment time. In the first 30 minutes of fungi decreased 0.33 log CFU/gr, 0.20 log CFU/g for 60 min treatment, and 0.08 log CFU/gr for 90 min treatment. While the 120-minute treatment, total fungi increased 0.32 log CFU/gr.

### 3.2.3 Chemical Substances of Rice Treatment

Application of ozone at doses that are sufficient for the effective decontamination of rice may affect various quality attributes. Ozonizing not universally beneficial and in some cases may promote oxidation degradation of chemical constituents present in the rice. Surface oxidation, discoloration or development of undesirable odours may occur from excessive use of ozone Mendez et al. [10].

![Figure 6: Chemical Substances of rice (water, fat, and protein) as function of treatment time with ozone flow of 0.5 liter/minute](image)
Chemical substances of rice treatment seriously should be studied. We present in figure 6, results of water fat and protein for rice before and after ozone treatment. It is indicated that there are no significant change of chemical substances in rice for the condition of this work.

3.2.4 Ozone Technology for Rice Storage System (OTRISS)

The results of research on the characterization of the reactor, characterization generator, ozone concentrations produced by ozone Generator relation to the required voltage and current generated is used for the operating voltage of OTRISS. The results obtained from rice treated with ozone with ozone concentration variation and its relation to the ability to kill bacteria and germs used to establish the concentration of ozone used. The selection of ozone concentration is very dependent on Generator used, high voltage used. Utilization of research results as a variation of ozone concentration specified time will result in a choice of container OTRISS ozonizing time. These options will result in an optimal use of energy and generating OTRISS ability to store rice was good, and does not affect rice quality. For certain ozone concentrations used for treatment, and treatment time have also been conducted chemical evaluation of rice. The results obtained still below the chemical elements contained minor changes and still within the scope of the relevant areas related to the content of the new milled rice. Results of integration between containers of rice, HV power supplies, ozone generators, blowers, further research is needed for the optimization of energy efficiency.

3.2.4 Realization of OTRISS Container

OTRISS containers have been realized with the size of 100 kg and 75 kg of rice. Containers made of stainless food standards. Figure 7 shows the containers that have been realized. In this study, all of the container is made of food standard stainless stainless. Figure 8 is a container on the size OTRISS beyond 40 cm x 40 cm x 80 cm, and the inside can carry about 75 kg of rice. OTRISS is equipped with an expenditure of rice from the bottom with a size of 300 grams and 600 grams, by pressing the knob towards the bottom and rice will fall and accommodated at the container placed at the bottom as retrieval system of rice.

![OTRISS Container equipped with a retrieval system of rice](image)

OTRISS drawing the inside is made of stainless steel punch with an aperture where rice can not get out, but ozone can enter. Through the holes in the ozone supplied to rice that has been put in containers (see figure ).
In this study also tried to realize OTRISS by utilizing waste refrigerator. The utilization of refrigerators which has long been recognized. Refrigerator has been becoming an important device in an urban house. At the moment, refrigerators have been becoming bearing waste very much. This waste can be used as the outer layer of OTRISS. The back of which is often used for placement compressor and power to the refrigerator, in OTRISS used to put the power and blowers, being at the bottom which is usually used for the placement of heavy tubers in refrigerator used to place the reactor. This system has been tested for ozone accumulate in the container of rice. Within 40 minutes, ozone accumulation in the space of 400 liters (50 cm x 50 cm x 80 cm) by 4 ppm constant. It is quite for treatment on rice that is inserted into the container.

4. CONCLUSION

Plasma for environmental applications can reduce gas emissions released by motorcycle and vehicle exhausts. This technology can reduce significantly emissions of SOx, COx, and NOx. Non-polluted plasma muffler prototype adaptation has done in four wheels and more vehicles. Pilot scale improvement has been done by integrating reduction system into vehicle muffler from it previous position outside the muffler. High voltage that used to develop plasma condition comes from 12 V 34 A accumulator which connected with electronic equipment and able to develop voltage up to 20 kV. Exhaust gases reduction Ability has done by varying engine rotation. Plasma muffler appearance in vehicle doesn't change outside dimension of its original muffler and it reactor placement in muffler has a function to change resonator chamber function and make this muffler still fulfill muffler standardization with more performance in reducing exhaust gases (COx, NOx, HC). Optimal reduction level made at 2200 rpm for COx is 88,52%. for CO is 88,93%, for HC is 97,34% and for NOx at 4800 rpm is 76,19%

In the agriculture, our results on plasma application indicated that Plasma Technology for Growth Stimulation of Seeds (PTGS) can reduce time for pre plantation of mangrove until 2.4 months. That's mean, the farmer can reduce cost pre plantation of mangrove and increase 43 % of the benefit for the farmer if we compare with before using PTGS. Moreover, resurveying the results of plantation mangrove base on Wanamina concept, we found that this concept enriched and enhanced macrobenthos, plants species, animal species and plankton species at Kaliuntu territorial waters, Pasar Bangi. Implementation of PTGS augmented self confidence of mangrove farmer community due to using new technology for products differentiation.

Rice storage technologies have not been able to ensure the resilience of rice in a certain period rather long. Often times the reported distribution of large quantities of rice had to be canceled because the rice has been damaged. Quality due to inadequate consumption of rice is especially alarming, because the government in this case "Bulog" can not replace the rice in a large amount in a short time, while on the other hand people need not be postponed. There is an increasing emphasis and trend toward the safe storage of food grains while minimizing qualitative and quantitative losses. Food laws and legislation to phase out chemical pesticides, increased pest resistance towards conventional fumigants. Ozone is an alternative method of rice disinestation which is environment friendly resulting in no toxic residues. Ozone offers unique advantages for rice storage with minimal or desired effects on the physicochemical properties.
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REFERENCES