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Ionizing radiation as a tool to protect environment

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ABSTRACT

The paper overviews possible ionizing radiation application for environmental pollution control. The laboratory, pilot plant tests and industrial applications have illustrated possibility of this technology application for gaseous, liquid and solid wastes purification and treatment. Especially electricity driven radiation sources like electron accelerators have a broad prospectus of their applications. The examples of ionizing radiation application to protect the environment and human health are discussed in the paper.

1. INTRODUCTION

The powerful tools of ionizing radiation, the gamma sources and the electron accelerators have been used for radiation processing of materials for more than half of the century [1,2,3,4]. However, the possibility of radiation application for environmental pollution control was realized in the 1970s, when the environmental protection agencies were established and standards on pollutants emission limits were set. The special input for the technology application was development of the new high power electron accelerators which can be used for the processing on line of the huge flow streams of liquid or gaseous pollutants. The accelerators were applied for off – gases and wastewater treatment [5,6] and biological sludge from a wastewater treatment plant disinfecting testing [7]. Gamma source application is related

to the last mentioned technology as well [8]. The technologies applying the particle accelerators are considered important for further high-tech processes in different fields of national economies ; material processing, sterilization of medical products, environmental protection, medicine (patient treatment and diagnosis, manufacturing of the radiopharmaceuticals), cargo inspection, chemical analysis, nuclear power (ADS and transmutation), etc [9].

2. INDUSTRIAL OFF-GASES PURIFICATION

The pollutants are emitted to the atmosphere with off-gases from industry, power stations, residential heating systems and municipal waste incinerators. Fossil fuels, which include coal, natural gas, petroleum, shale oil and bitumen are the main source of heat and electric energy. Recently the main fuel for renewable energy production in heat boilers is biomass as well. All these fuels contain, besides major constituents (carbon, hydrogen, oxygen), metal, sulfur and nitrogen compounds.

During the combustion process different pollutants such as fly ash, sulfur oxides (SO_2 and SO_3), nitrogen oxides (NO_x = NO_2 + NO), hydrochloride (HCl), and volatile organic compounds, including chlorinated species are emitted. Fly ash contains different trace elements (heavy metals). Mercury is emitted in adsorbed or free forms.

Gross emission of pollutants is tremendous in most countries all over the world. These pollutants are present in the atmosphere in such conditions that they can affect man and his environment. Air pollution caused by particulate matter and other pollutants not only acts directly on environment but by contamination of water and soil leads to their degradation. Wet and dry deposition of inorganic pollutants leads to acidification of environment. These phenomena affect health of the people, increase corrosion, destroy forests and plants.

Different air pollution control technologies are searched for. However the technologies which treat different pollutants in one step are of special interest. The electron beam treatment technology is such a process.

After irradiation of polluted gas , fast electrons interact with gas creating various ions and radicals, the primary species formed include e^-, N_2^+, N^+, O_2^+, O^+, H_2O^+, OH^+, H^+, CO_2^+, CO^+, N_2^*, O_2^*, N, O, H, OH, and CO. In the case of high water vapour concentration the oxidising radicals $OH^\cdot$ and $HO_2^\cdot$ and excited ions as $O(^3P)$ are the most important products. The SO_2, NO, NO_2, and NH_3 present cannot compete with the reactions because of very low

concentrations, but react with N, O, OH, and HO_2 radicals. Ammonia mentioned above is added to the gas to neutralize acids formed in reaction, aerosol of ammonium sulfate and nitrate are the final product of the reaction. The interaction of electrons with gas forms visible cold plasma (Fig.1).

Fig. 1. The visible light glow indicates that the cold plasma is formed inside the process vessel in which gas is irradiated.

The electrons are introduced to the process vessel via thin 50 μm titanium foil. The scheme of flue gas treatment process is presented below (Fig.2).

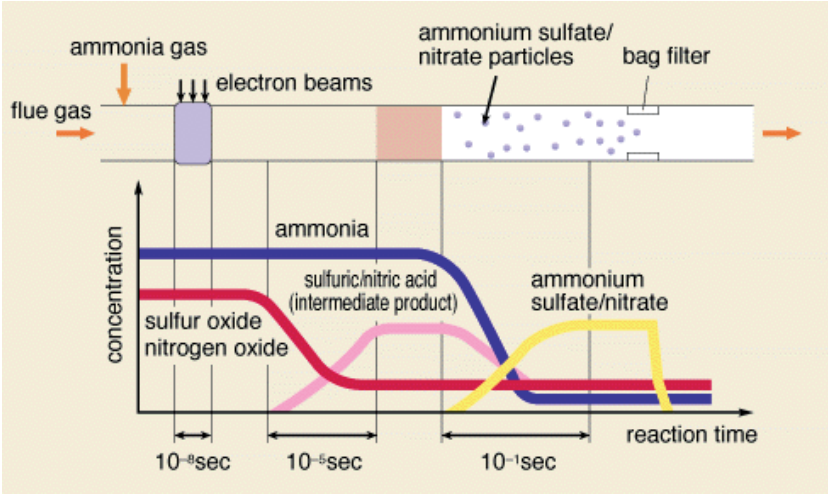

Fig. 2. The scheme presenting sequences of the physicochemical reactions which lead to acidic pollutants removal and solid fertilizer particles formation.

The pilot plant with the maximum flue gas flow rate 20,000 Nm^3/h, equipped with two accelerators emitting 700 keV electrons, 50 kW beam power each was constructed and tested at the end of the 20th century in EPS Kaweczyn. The full scale industrial plant of the gas flow rate 270,000 Nm^3/h, was constructed at EPS Pomorzany, Szczecin. In this case the beam power of four accelerators installed exceeded 1 MW. In both cases the purified flue gases were emitted from coal fired boilers.

The other laboratory tests have proved the applicability of the technology to treatment of flue gases from oil fired boiler [10] and feasibility of the process application for the mercury (in flue gas) treatment [11].

3. WASTEWATER TREATMENT

Because of the increasing levels and complexity of polluted effluents from municipalities and industry, current wastewater treatment technologies are often not successful for the remediation of polluted waters and disinfection. The development and implementation of alternative technologies for the clean up of industrial wastewater, municipal water, groundwater and drinking water is critical to the sustainability of many countries.

The water purification process uses a product of water radiolysis (Fig.3) in the pollutants degradation [12].

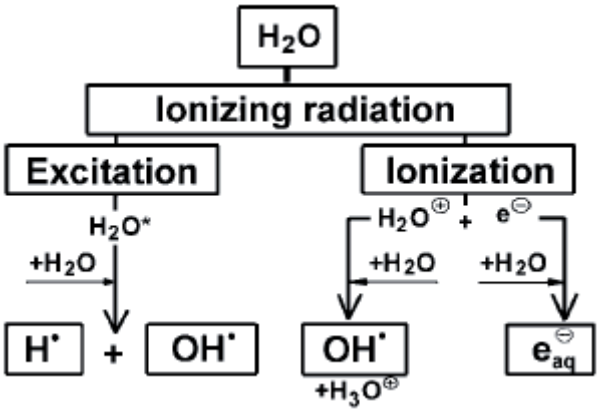

Fig. 3. Water radiolysis; main active species formed.

Some of these free radicals formed are oxidative species ($^{\cdot}OH$) and the other reductive (H, e^-_{aq})ones. Therefore there are competition between oxidation and reduction processes in the system, application of synergy with ozone

may improve the overall efficiency of organic pollutants destruction. In this case the ozone reaction with the strong reductive species leads to hydroxyl radicals formation (Fig.4) [l3].

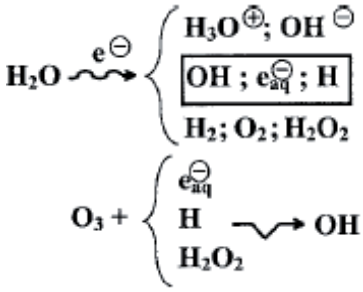

Fig. 4. Reactive species formation by ionizing radiation in the presence of ozone.

Aqueous effluents that have been treated by irradiation include polluted drinking water, liquid industrial and agricultural wastes. However, attention must be paid to the toxicity of the by-products formed in the process, which is the main limitation of its implementation [14]. The industrial plant has been constructed on South Korea. Based on the data obtained in the laboratory and pilot plant experiments, the suitable doses were determined as around 0.2 kGy for the flow rate of 10,000m^3 effluent per day.

4. BIOLOGICAL SLUDGE DISENFECTION

The problem of water contamination by chemical and biological matters is a well-known problem. Due to the fact that in many regions deficit of water for municipal, agricultural and industrial use is observed, the water from the reservoirs, mainly rivers is reused many times. Therefore the perfect purification and disinfection is necessary to protect health of the consumers, even so bottled water and household filters are very popular as a source of good quality of the drinking water.

The most popular and efficient for wastewater purification are biological treatment plants. These plants, as a result of the process, are a source of biological sludge which is a waste (approximately 3% of solids , if not dewatering process is applied). Unfortunately the sludge which is of municipal wastewater origin is biologically contaminated by viruses, bacteria and eggs of parasites. In the case of landfill storage these contaminants survive for

many years , due to the fact that even in the region with severe winters, the sludge undergoes continuous fermentation and temperature is much higher than the water freezing point. Some years back, different countries solved the problem by sea dumping, which is prohibited nowadays. The sludge is a good organic fertilizer, especially good for sandy soils applications, so some countries apply an under soil level injection, which is not so safe from the health point of view if the field is used for cultivation of food industry crops. Therefore in the EU sludge incineration is the main direction to solve the problem, however, all combustion processes do emit pollutants and greenhouse effect gases to the atmosphere.

Different methods of disinfection are proposed; heat pasteurization, mixing with lime and ionizing radiation treatment. The radiation treatment of food items [15] and medical products [16] treatment. In the first case low doses are applied to control microbiological contamination of the consumable product (e.g. spices) and in the second case much higher doses are applied to obtain microbes free product. The destruction of the microbes takes place by the direct and indirect DNA double and single strand breaks and other cell components damage. Again due to the high concentration of water in a living organism the free radicals formed play the most important role in the indirect damage of living organism structure. The indirect action of ionizing radiation, so similar to the discussed earlier for non-living physicochemical matter, is presented in Fig.5.

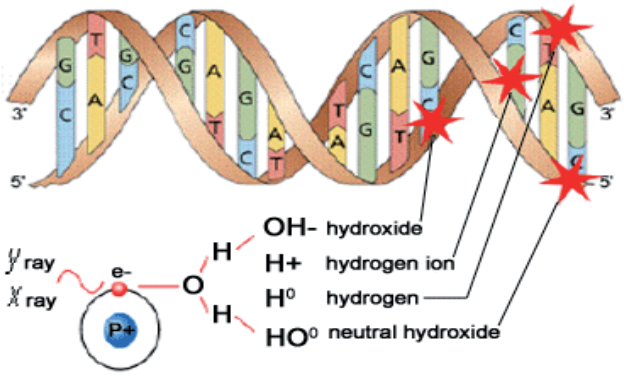

Fig. 5. Indirect (via free radicals formed) DNA damage by ionizing radiation.

Research has shown that sewage sludge can be disinfected successfully by exposure to high-energy radiation. Doses of 2-3 kGy destroy more than

99.9% of bacteria present in sewage sludge. Higher doses (up to 10 kGy) are required to inactivate more radiation resistant organisms. Both gamma sources (Co-60, Cs-137) and electron accelerators can be used for the irradiation of sewage sludge. Gamma sources have better penetration allowing thicker layers of sludge to be irradiated, although they are less powerful and take longer irradiation time than electron sources. The irradiated sludge being pathogen free can be beneficially used as manure in the agricultural fields as it is rich in nutrients required for the soil. Initial field trials of sludge as manure in agriculture fields in winter wheat crops as well as in summer green gram crops have been very encouraging. Since the irradiated sludge is free from bacteria, this can also be used as a medium for growing soil useful bacteria like rhizobium and azetobactor to produce bio-fertilizers, which can be used to enhance the crop yields.

5. CONCLUSIONS

The application of ionizing radiation may be an important technique for environmental protection. Especially electron accelerators can be a powerful tool in technology development, which requires multidisciplinary approach to solve many still existing problems.

> "More than 30,000 particle accelerators are in operation around the world, serving medicine, industry, energy, the environment, national security, and discovery science. As accelerator science and technology continue to advance, so too will their benefits to society"[9].

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