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Advanced treatment solutions intended for the reuse of livestock wastewater in agricultural applications

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Abstract. One of the main concerns of the developing world is the mitigation of pollution of environmental components together with the recovery and reuse of valuable substances from waste resulting during diverse anthropic activities. Wastewater generated by agro-zootechnic activities is a source of nutrients (nitrogen and phosphorus compounds) and traditionally it is reused for crops irrigation. However adverse effects on the environment may be caused should a proper treatment not be performed, considering the spread of additives/drugs altering the natural metabolism in modern livestock industries and subsequently their presence in waste. In this context, research was conducted on laboratory scale setups of some advanced treatment processes for wastewater resulting from cattle farms. UV disinfection and oxidation using ozone were investigated in order to emphasize the antimicrobial effect and their contribution to the improvement of water quality. The permissible irrigation water quality which varied based on the crop type was the decisive factor in adjusting the experimental setup and effluent quality. The results have revealed the inactivation of bacteriological indicators up to 99% and even 100% in the case of faecal coliforms and faecal streptococci. Moreover, ozonation allows also the removal of organic matter, with an efficiency of over 80%. This research offers solutions suitable for areas where the water demand exceeds availability and in the regions affected by drought.

1. Introduction

Availability and quality of water resources are key issues of water management and the protection and conservation of water resources have become a requisite for sustainable development. The increasing demand of water in agricultural and industrial purposes together with higher frequency of extreme meteorological phenomena, such as lack of precipitations, and eventually higher occurrence of droughts, exert pressure on the availability and quality of water resources. In this context, the reuse of reclaimed wastewater is a compelling alternative, particularly in the areas affected by water shortage and drought, as it may provide partially the water requirements and thus enable the protection and conservation of water resources. Reclaimed water may be reused in diverse purposes, commonly irrigation, industrial and urban uses. In the context of the occurrence of hazardous substances in the environment and of the more and more stringent legislative provisions, wastewater treatment prior to their discharge in the environment is compulsory. The selection of appropriate treatment methods is challenging, particularly in the case of wastewater containing hazardous and emerging pollutants, as these substances are of a complex nature and conventional wastewater treatment processes are unable to remove them efficiently [1–16].

Wastewater resulting from agro-zootechnic activities has been used traditionally for crop irrigation as it provides useful elements for the plants. However, issues concerning the microbial contamination and potential presence of additives/drugs that alter the natural metabolism in such wastewater arise and its reuse is subjected to various restrictions. Usually, the treatment of wastewater resulting from livestock farming is achieved by means of conventional aerobic/anaerobic biological processes. This treatment provides insufficient reduction of organic load, particularly of hardly degradable substances. Moreover, the effluent quality requirements in respect to microorganisms are not achieved. Thus, the use of advanced treatment methods such as advanced oxidation or membrane processes, together with the inactivation of pathogens within an additional disinfection step is required prior to the application of the treated effluent on soil [1–11, 17-26].

The selection of the disinfection method should take into consideration its efficiency, costs, site-specific conditions, environmental and health aspects. For the wastewater reused in irrigation purposes, the quality requirements specific for the type of crop intended to be irrigated should also be considered. Generally, disinfection may be performed by thermal, physical and chemical means. Commonly, chemical disinfection and UV irradiation are used. Chemical disinfection is based on the addition of some reagents with antimicrobial action, such as chlorine, chloramines and ozone. Among these, chlorination has been used for water and wastewater treatment for many years as it is an efficient and reliable disinfection method. In the recent years, toxic chlorination by-products were identified and alternative disinfection processes such as ozonation and UV irradiation have been investigated and employed more frequently [17, 19, 20, 27-36].

Ozonation is based on the disinfecting action of ozone, which is a strong disinfectant that allows the inactivation of pathogens, even the ones that show resistance to other disinfection agents. Moreover, ozone has strong oxidation capacity and may increase the biodegradability of organic compounds, including the compounds that react to a very small extent to conventional oxidation processes, thus enabling their degradation. The efficiency of the ozonation depends on the ozone dose, contact time and wastewater characteristics. Alternative ozonation systems use ozone in conjunction with other oxidizing agents, mainly hydrogen peroxide, or with a catalyst, such as unsupported and supported metals and metal oxides. The use of hydrogen peroxide may enhance the ozone decomposition cycle, thus accelerating the efficiency of the process, as the hydroxyl radicals generated in the decomposition process react also with the organic matter from wastewater [17, 19, 20, 27, 29-32, 37-40].

Disinfection by UV irradiation is an efficient and cost-effective method that enables the inactivation of pathogens without generating toxic by-products. However, it has no effect on the chemical contaminants from wastewater. The use of UV light has some advantages such as lack of chemical consumption, low contact time, reduced space and low energy requirements. The efficiency of UV irradiation is higher compared to the conventional chlorination process and it depends on the intensity of UV radiation, contact time and wastewater characteristics. The efficiency of UV disinfection may be decreased in cases of wastewater with high particles content, as they block the penetration of UV light. UV disinfection is less effective for wastewater with total suspended solids above 30 mg/L. Moreover, the reactivation of the microorganisms may occur following the UV treatment [20, 27-29, 33, 34].

Considering the abovementioned aspects, the suitability of selected disinfection methods for the treatment of wastewater resulting from livestock farming was investigated at laboratory scale. This paper presents the results of UV disinfection and oxidation using ozone for wastewater resulting from cattle farms. The antimicrobial effect and the contribution of the investigated methods to the improvement of water quality are depicted.

2. Materials and methods

The objective of this paper was accomplished by means of an experimental study consisting in the treatment of wastewater resulting from livestock farming at laboratory scale, using two processes that enable wastewater disinfection, namely UV irradiation and ozone oxidation.

UV treatment is based on the primary action mechanisms of UV radiation on the microorganisms, by destroying the cell's nucleic acids after photochemical reactions. Low pressure mercury lamps are commonly used as UV radiation sources. These lamps emit approximately 92% of the light at 254 nm, the optimum wavelength at which the germicidal action is best. The experimental setup for the UV treatment consisted of a reactor provided with a 55 W lamp that was operated in discontinuous mode with active recirculation of the wastewater (Figure 1).

Figure 1. Experimental setup used for the UV treatment of wastewater.

Ozonation is based on the enzymatic action of ozone on the microorganisms from wastewater by altering the redox processes that take place within the cell. The setup employed for the treatment comprised three units (Figure 2):

- ozone generation unit;
- contact unit/ozonation reactor;
- unit for the retention of unreacted ozone.

The ozone generation unit provides the required reaction gas by ionising the oxygen from air in Corona-type electric discharge. The operating conditions for the ozone generation unit were: generated ozone quantity = 5.7 g/h determined by the iodometric method in the experimental setup.

The ozonation reactor is a bubble column-type reactor operated in continuous mode with a wastewater flowrate of approx. 3 L/h. The treatment is performed in two steps and the ozone is fed in counter flow to the wastewater flux.

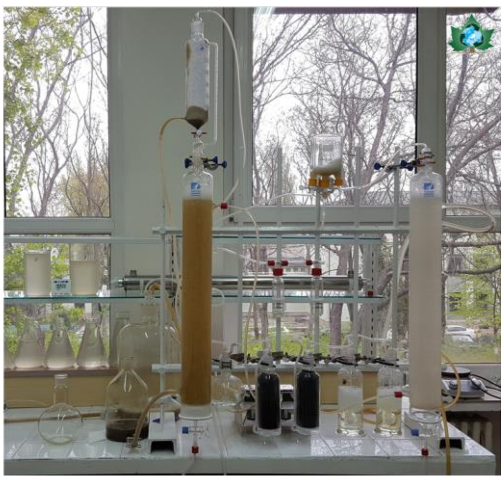

Figure 2. Experimental setup used for the ozonation of wastewater.

The unit for the retention of unreacted ozone consists of two absorption columns provided with granular activated carbon and two columns provided with indicator solution (c = 10 mg KI/L). The mass transfer between the gaseous phase and the liquid phase is not fully accomplished in the ozonation reactor and some of the generated ozone is found in the residual gas. Ozone is retained within the retention unit and destroyed prior to the discharge to the atmosphere.

The treatment was applied on wastewater resulting from a medium size dairy farm. Wastewater was collected and stored in a lagoon and was thus subjected to physical separation of suspended matter and aerobic-anaerobic biochemical degradation of organic substances prior to the UV and ozone treatment.

Water quality parameters were determined using standardised methods based on conventional and instrumental techniques, as follows: pH (ISO 10523:2009), conductivity (EN 27888:1997), COD (ISO 6060:1996), BOD (EN 1899:2003), total and faecal coliforms (ISO 9308-2:1990), enterococci (EN ISO 7899-2:2002), antibiotics (EPA 1694:2007, UHPLC on-line SPE Thermo Scientific E Quan MAX Plus LC-MS / MS TSQ Quantiva).

The study on the behaviour of wastewater resulting from livestock at the two treatment methods consisted in the assessment of the efficiencies for the removal of specific pollutants in conjunction with the changes in organoleptic properties of the effluents. The experimental results were evaluated taking into consideration the recommendations provided by ISO 16075:2015 regarding the use of treated wastewater in irrigation purposes [38]. The efficacy of the proposed technological solutions are a key factor in ensuring the compatibility between the quality of treated wastewater and their use in order to prevent or minimise the potential contamination of soil and groundwater or surface water sources.

3. Results and discussions

The methods proposed for the treatment of livestock wastewater investigated within this study were UV disinfection and ozonation (O_3) vs. ozonation in conjunction with hydrogen peroxide (H_2O_2). The later was conducted in order to observe the potential enhancing effect on the oxidation process. The curves illustrating the variation of the pollutants concentration corresponding to a treatment time of 120 min are shown in figures 3-6.

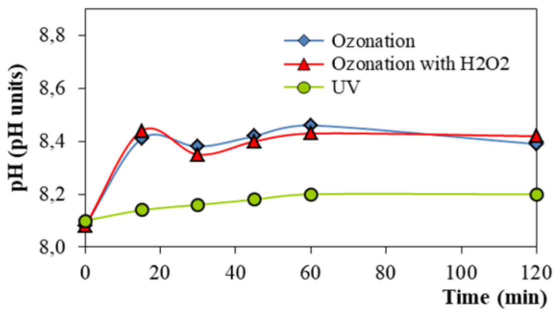

Figure 3. pH variation during the wastewater treatment processes.

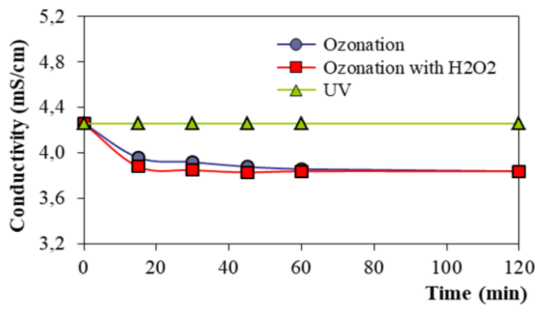

Figure 4. Conductivity variation during the wastewater treatment processes.

As one may see in Figure 8, between ozonation with/without hydrogen peroxide is almost no difference in the evolution of pH, conductivity, COD and BOD. In both cases, the degradation of pollutants proceeds with near the same rate and efficiency. All the results obtained confirm that hydrogen peroxide added in reasonable doses does not have a significantly and positive effect on the efficiency of wastewater treatment. Also, the UV radiation alone is unable to reduce significantly any pollutant concentration.

In order to evaluate the behaviour of some antibiotics (ampicillin and gentamicin) to the investigated treatment methods, fortified samples were prepared by dissolving a known quantity of pollutant (1 mg/L) in the tested wastewater. Ozonation accomplished their degradation up to ultra-trace levels.

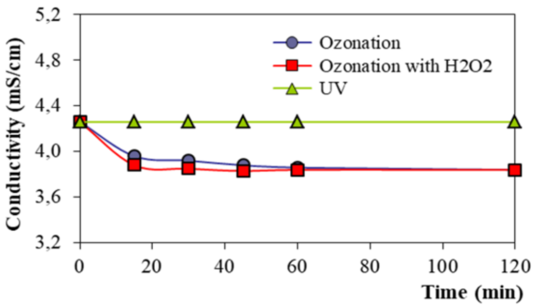

Figure 5. COD variation during the wastewater treatment processes.

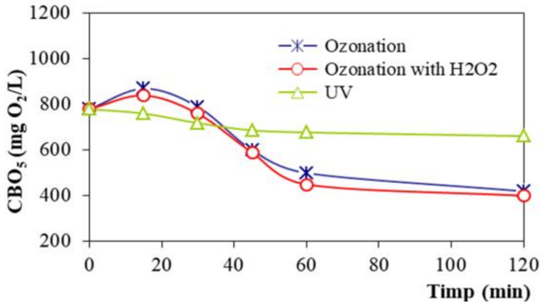

Figure 6. BOD variation during the wastewater treatment processes.

As regards the disinfecting effect of the proposed methods, the results showed that the efficacy of the ozonation process is superior compared to UV irradiation. This reflects particularly on the inactivation of faecal coliforms and enterococci, where efficiencies of 100% were achieved (Figures 7-8).

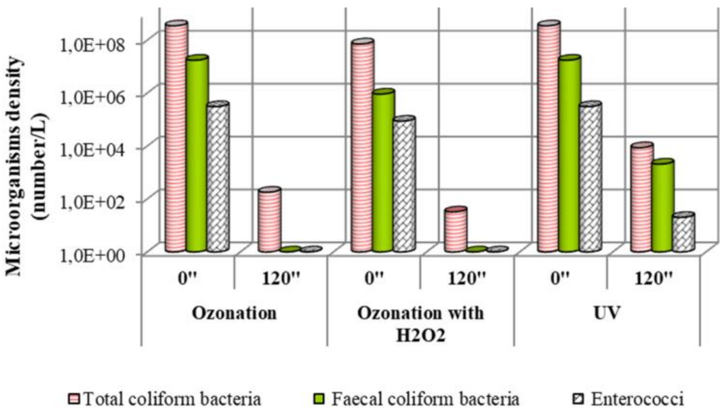

Figure 7. Variation of bacteriological indicators during the wastewater treatment processes.

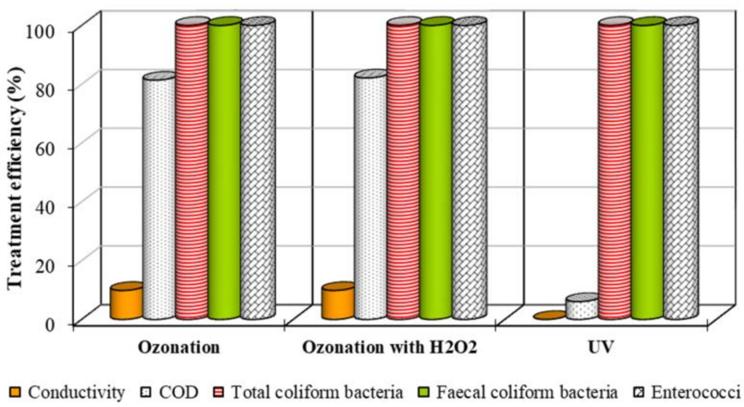

Figure 8. Comparison between the treatment efficiencies of UV irradiation and ozone oxidation of livestock wastewater.

The efficiency of wastewater treatment is affected by a series of factors, such as: physical characteristics of wastewater, intensity of UV radiation, applied ozone dose, contact time etc. A comparative analysis of the results obtained for the application of the investigated processes for the treatment of livestock wastewater is depicted in Figure 8.

4. Conclusions

Reuse of treated wastewater in various purposes is a necessity in the areas with low availability of water resources from the view of water preservation. Livestock farming generates wastewater with high content of nutrients and organic compounds. Considering the location of these facilities in the vicinity of agricultural areas, the reuse of treated wastewater in fertirrigation purposes represents an option for the recovery of these outflows, which contributes to the achievement of the objectives of sustainable management.

The selection of optimum solutions for the treatment of this type of wastewater with complex matrix should take into account the specific characteristics of the soil and crop intended to be irrigated. Various treatment methods are employed for pollutant removal, however an advanced treatment is imperative so that the final effluent is suitable.

This paper highlighted the behaviour of wastewater resulting from a dairy farm to tertiary treatment by means of UV irradiation and oxidation using zone. The tested wastewater had been previously subjected to natural biological treatment within an aerobic-anaerobic facultative lagoon. The results proved the antimicrobial effect of both methods, with high efficiency of ozonation in case of wastewater with high microbial contamination (log unit reduction up to 6 for total coliforms and complete inactivation of faecal coliforms and faecal streptococci). Additionally, in the case of oxidation with ozone, the removal of colour and specific odour was observed, up to an acceptable level from the point of view of the perception of population from the areas where the irrigation with this type of wastewater is performed. As regards the organic load of the effluents, UV disinfection showed no changes of COD, while ozonation attained removal efficiencies of up to 80%. Also, ozonation enabled the oxidation of organic compounds increasing its biodegradability and it provided a removal of antibiotics such us ampicillin and gentamicin up to ultra-trace level.

Each of the investigated methods has some advantages and drawbacks that should be taken into account when establishing the optimum solution, based on the actual status of the preliminary treatment to which the wastewater is subjected locally and the final designation of the effluent (type of crop). UV disinfection has lower costs and does not require the use of chemicals; however the performance of the process may be reduced by high content of suspended matter and biofilm formation. On the other hand, ozonation has higher costs and difficulty in operation; however it provides a more efficient inactivation of bacteria, viruses and protozoa, together with the improvement of the organoleptic properties of treated wastewater.

Investigations on combining the methods described by this paper with complementary methods need to be performed for improving the efficiency of the tertiary step so that the protection of environmental compartments is ensured in cases when the effluent is applied in vulnerable areas and/or over a long period of time.

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