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Maximizing Enhanced Ozone Oxidation of Pulp Mill Effluents

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by

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EXECUTIVE SUMMARY

Most of the experimental studies have been conducted. Those studies included: (1) hydrodynamics of the ozone bubble column, (2) mass transfer in three different sizes of the gas sparging systems (venturi injectors), (3) mass transfer in the ozone-jet bubble column, and (4) ozone auto-decomposition kinetics in a batch system. Three analytical models have been derived for modeling the hydrodynamic behavior of the bubble column, are being tested against the collected experimental data. Six analytical models, have been derived for modeling the overall performance of oxygen and ozone bubble columns for clean water and for pulp mill effluent treatment. Those models have been initially tested against experimental data obtained in the past in a fine-diffuser bubble column that had been operated at the Environmental Engineering Laboratory of the University of Alberta. Those models have shown an excellent agreement with the experimental data. Those models are being tested against the experimental data for the water treatment conditions in the jet-bubble column. The last two experimental studies including the ozone mass transfer and colour and chlorinated organic compounds reduction in pulp mill effluents and bubble size determination in pulp mill effluents using the Laser Doppler Anemometer (LDA) are undergoing and are expected to be completed in the next two months.

Three papers have been submitted for publication in the *Ozone Science & Engineering Journal* and *Journal of Advanced Oxidation Technologies*. Four conference papers have been accepted for conference oral presentations and publication in the conference proceedings.

Five different papers are in the preparation process for submission in the *Ozone Science & Engineering Journal*, *Journal of Environmental Engineering, ASCE*, *Water Research Journal*, and *Journal of Environmental Technology*.

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INTRODUCTION

There has been increasing concern about the environmental impact of chemical compounds created in the pulping and bleaching processes. In particular, the colour-causing and chlorinated organic compounds that are found in pulp mill effluents at high concentrations have been identified as the major source of concern. This is mainly because some of these compounds may be toxic and/or resistant to conventional biological treatment processes. A substantial number of these compounds can be carried through biological treatment processes into mill effluents, discharged into the receiving environment, and thus, could cause harm to the aquatic communities depending on the characteristics of the receiving environment. Thus, leading to inconsistency with maintaining the ecological integrity of the boreal forest, preserving and improving the Canadian public and environmental health. Studies into methods of reduction of these compounds have taken many directions including advanced oxidation processes (AOP). One method of advanced oxidation processes, ozonation, when used on pulp mill effluents, has shown some important characteristics that supplement the normal mass transfer process. With the recent advances in ozone generating technologies and the development of highly efficient ozone contacting technology, which allows for enhanced ozone mass transfer, the application of ozonation for pulp mill effluent treatment becomes not only technically feasible, but also economically viable.

The scope of the proposed research was intended to study the ozone-gas-liquid mass transfer process in order to optimize this process in a highly reactive environment, such as pulp mill effluents. This project is actually a continuation of the project, that started in 1990, which led to major projects in 1995, 96, and 97. These projects dealt with improving the ozone mass transfer process in treating pulp mill effluents for colour reduction and treatability improvement. That work identified the fact of potentially using enhanced mass transfer concept to reduce the cost and improve the performance of the treatment process.

A newly developed jet-bubble column, (injector-contactor) that utilizes venturi injectors has been used for the ozone mass transfer and colour reduction applications. The venturi injectors are utilized to create jet flows in the ambient fluid. One of the techniques for using venturi injectors is to have the intersecting of jets causing an increase in the turbulence produced in the liquid phase and thus, increasing the gas-liquid mass transfer. Along with enhancing the turbulence for more gas-liquid mass transfer, the other contactor characteristics that influence the process will be studied. Those characteristics include: gas-liquid-jet ejector placement, the angle between the intersecting jet ejectors, gas and water flows, and gas to liquid ratio. Also, the ozone decomposition and decay kinetics are important in the prediction of the performance of the ozone contactors. That research will help maximize the efficiency of the ozone mass transfer and consequently the treatment processes that involves ozone gas application. Understanding both the ozone chemistry and the hydraulics of the ozone gas transfer process will help build mathematical models of ozone mass transfer for different systems of ozone contactors. By incorporating the different factors into the design of ozone contactors, we have obtained well-optimized designs and operational conditions for the ozone contactor. The performance of such jet injection contactor can be predicted using the developed models.

Since the ozone oxidation efficiencies for pulp mill effluent organics can be estimated by the utilized ozone, it is important to determine the ozone absorption rate from which utilized ozone can be calculated. The overall mass transfer coefficient (k_La) has been evaluated in terms of the local mass transfer coefficient (k_L) and the bubble surface area (A). Studies comparing oxygen mass transfer and ozone mass transfer have shown that the mass transfer enhancement is occurring when ozone is used to treat pulp mill effluents. Ozone gas in some environments, such as pulp mill effluents, can be expected to follow the fast or instantaneous kinetics regime. Thus, the occurrence of rapid ozone decay reactions will reduce the concentration of dissolved ozone in bulk liquid, therefore, increasing the driving force of the ozone mass transfer from the gas phase into the liquid phase and as a result, the mass transfer process will be enhanced by an enhancement factor (E). Due to the fast ozone decay reactions, the absorbed ozone may be depleted completely within the liquid film at or just beneath the gas-liquid interface and as a result, a high enhancement factor will be achieved. Previous research, that has been conducted at the University of Alberta, on ozonation of pulp mill effluents has identified the fact of potentially using enhanced ozone mass transfer concept to reduce the cost and improve the performance of the ozone treatment process. In this research, it was found that the Ek_La values varied substantially during the course of ozonation, indicating that the enhancement factor was not only affected by operating conditions, but also related to wastewater characteristics. The better mass transfer due to the increased turbulence, i.e., mixing by using intersecting turbulent jets (venturi injectors) has been reflected in the k_La value. As a result of the expected enhancement of the ozone mass transfer process and the use of this new ozone injection technology, a modified overall mass transfer coefficient (Ek_La), that has been developed in that earlier research on ozone bubble columns, is being evaluated for this new ozone injection technology.

DATA ANALYSIS

The simulated numerical data analysis has been finished and the rest of the experimental data analysis is underway to verify the findings that have been observed from the simulated numerical data and to finally test the model predictions after being tested initially against some historical experimental data.

Some of the data analysis can be found in the accepted refereed-conference papers and the submitted refereed-journal papers.

APPENDIX (I)

Refereed Conference Papers

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El-Din, M.G. and D.W. Smith. Rational approach to hydrodynamic modeling of an ozone jet-bubble column.

El-Din, M.G. and D.W. Smith. Comparing ADM and BFCM for modeling ozone bubble columns with constant dimensionless operating parameters.

El-Din, M.G. and D.W. Smith. Ozone mass transfer in water treatment: Hydrodynamics and mass transfer modeling of ozone bubble columns.

El-Din, M.G. and D.W. Smith. Designing ozone bubble columns: A spreadsheet approach to axial dispersion model.

APPENDIX (II)

Submitted Refereed Journal Papers

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El-Din, M.G. and D.W. Smith. Development of transient backflow cell model (BFCM) for bubble columns.

El-Din, M.G. and D.W. Smith. Theoretical analysis and experimental verification of ozone mass transfer in bubble columns.

El-Din, M.G. and D.W. Smith. Designing ozone bubble columns: A spreadsheet approach to axial dispersion model.