

APPLICATION OF HYDRODYNAMIC CAVITATION FOR LEACHATE OF MUNICIPAL LANDFILL SITE

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Abstract. Landfill leachate is generated as a result of rainwater percolating through the landfilled waste and leaching organic and inorganic compounds formed during landfill transformation. Typically, landfill leachate is characterized by a high concentration of organic carbon (with an average COD of about 8000 mg O₂/L) and total nitrogen, mainly in the form of ammonia nitrogen (with an average NH₃-N of about 1600 mg/L). There are also present some toxic refractive compounds, like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and heavy metals. Usually conventional treatment such as activated sludge method is insufficient to effectively remove contaminants contained in landfill leachate. Thus in recent years advanced oxidation processes have been more widely applied to oxidize these contaminants. One of these methods, in which reactive hydroxyl radicals with a high oxidizing potential are formed, is hydrodynamic cavitation.

The paper presents preliminary research concerning the application of hydrodynamic cavitation in landfill leachate treatment. During the experiment the influence of changes of temperature on the process efficiency was examined. Moreover, changes in essential process parameters, namely TOC and COD were analyzed.

Keywords: hydrodynamic cavitation, landfill leachate, advanced oxidation processes

1. Introduction

Landfilling is considered to be the simplest and the cheapest method of disposing solid urban waste (Renou *et al.* 2008). Modern landfills are highly engineered facilities designed to minimize the adverse impact of the waste on the environment. However the generation of contaminated leachate remains an inevitable consequence of the existing landfills (Wiszniewski *et al.* 2006).

Landfill leachate is generated as a result of rainwater percolating through the landfilled waste and leaching organic and inorganic compounds formed during landfill transformation (Renou *et al.* 2008). Composition of landfill leachate is highly variable and depends on many factors such as refuse characteristics, hydrology of the site, climate, season, age of the site, height of refuse, and moisture routing through the refuse. However, three types of leachate can be basically distinguished depending on the landfill age (Kurnivan *et al.* 2006). The classification is shown in table 1.

Typically, leachate from young landfills is characterized by a large amount of biodegradable organic matter, high values of chemical oxygen demand (COD) and total nitrogen (TN), mainly in the form of ammonia nitrogen (NH₃-N). The ratio of biochemical oxygen demand to chemical oxygen demand (BOD₅/COD) decreases rapidly with the aging of the landfill. Moreover leachate may

contain some toxic refractive compounds, like polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and heavy metals (Kurnivan *et al.* 2006).

Table 1. Landfill leachate classification according to the age (Abbas *et al.* 2009)

	Young < 1 year	Medium 1-5 years	Old > 5 years
pH	< 6.5	6.5-7.5	> 7.5
COD (g/L)	> 15	3.0-15	< 3.0
BOD ₅ /COD	0.5-1.0	0.1-0.5	< 0.1
TOC/COD	< 0.3	0.3-0.5	> 0.5
NH ₃ -N (mg/L)	< 400	400	> 400
Heavy metals (mg/L)	> 2.0	< 2.0	< 2.0
Biodegradability	Important	Medium	Low

Generally, the treatability of landfill leachate greatly depends on the age of the landfill. Conventional treatment such as activated sludge method is rather insufficient to effectively remove contaminants contained in old landfill leachate. Biological processes are preferred for the treatment of leachate with the high ratio of BOD₅/COD, in turn, physical and chemical methods have been suggested

for the treatment of old and dilute leachates with low biodegradability (Kılıç *et al.* 2007).

As a consequence, in recent years, advanced oxidation processes (AOPs) has been more widely applied to oxidize leachate contaminants from old landfills. AOPs are defined as the oxidation processes that generate hydroxyl radicals (OH^\bullet), which are a non-selective oxidant and effectively degrade many refractory organic pollutants with high reaction rates. Most of these methods use a combination of strong oxidants – O_3 , H_2O_2 , irradiation, ultraviolet (UV), ultrasounds (US) and catalysts (Abbas *et al.* 2009; Derco *et al.* 2010; Renou *et al.* 2008; Tizaoui *et al.* 2006). One of these methods, in which reactive hydroxyl radicals with a high oxidizing potential are formed, is hydrodynamic cavitation.

Hydrodynamic cavitation is generated by the passage of the liquid through an orifice plate, which causes the kinetic energy of the liquid to increase at the expense of the pressure (Gogate 2008). Highly reactive free radical formation takes place as a result of the generation of microbubbles and their subsequent collapse due to pressure field variations in the solution (Chakinala *et al.* 2008). Cavitation technology has many advantages, the most important of which is a simple design resulting in minimal maintenance costs as well as no off gas treatment requirement. The only energy costs result from the use of the pumps to create pressure (Loraine 2007).

There are not many reports that indicate the application of hydrodynamic cavitation for wastewater treatment. Jyoti and Pandit (2003; 2004) investigated cavitation for water disinfection and concluded that cavitation is an energy efficient and economic technique in comparison to other conventional non-chemical water treatment. Kalumuck and Chahine (2000) studied destruction of p-nitrophenol in recirculating flow loops using a variety of cavitating jet configurations and operating conditions. Chakinala *et al.* (2008) studied the applicability of combination of hydrodynamic cavitation with the advanced Fenton process for industrial wastewater treatment and they noticed about 60-80% removal of TOC.

The paper presents preliminary research concerning the application of hydrodynamic cavitation in landfill leachate treatment.

2. Materials and methods

Equipment

Fig 1. shows the schematic representation of hydrodynamic cavitation reactor set-up. The system used in this experiment consists of a tank with the capacity of 30 L (1) connected with the pump WILO MVIE 200-1/16/E/3-2-2G (2), which allows to recirculate leachate within the hydrodynamic cavitation reactor (5). The pump flow is measured by electromagnetic flow meter Badger Meter Inc M1500AA (3). The other components of the system are manometer (4) and valves (6).

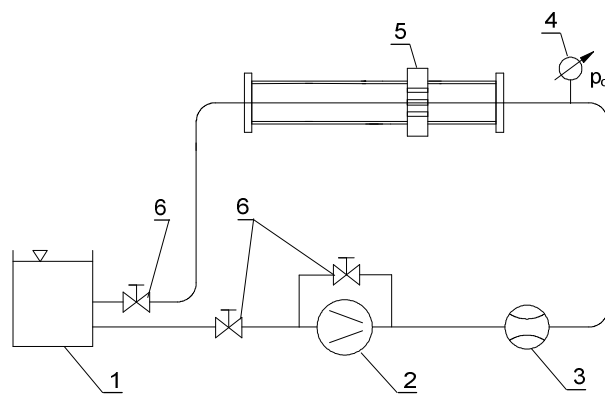


Fig 1. Experimental set-up: 1 – 30 L tank, 2 – rotor pump, 3 – electromagnetic flow meter, 4 – manometer, 5 – hydrodynamic cavitation reactor, 6 – valve

Cavitation reactor is presented in Fig 2. The main part of the reactor constitutes the inductor of cavitation (3) which is a steel orifice plate with four rectangular holes, each of them in size of 5x1mm. The reactor is composed mainly of acrylic glass pipe (2) and steel casing (1, 4). The circulating flow rate was 46.5 L/min, while the total volume of aqueous solution was 40 L. The pressure in the system was maintained at the level of 7 bar.

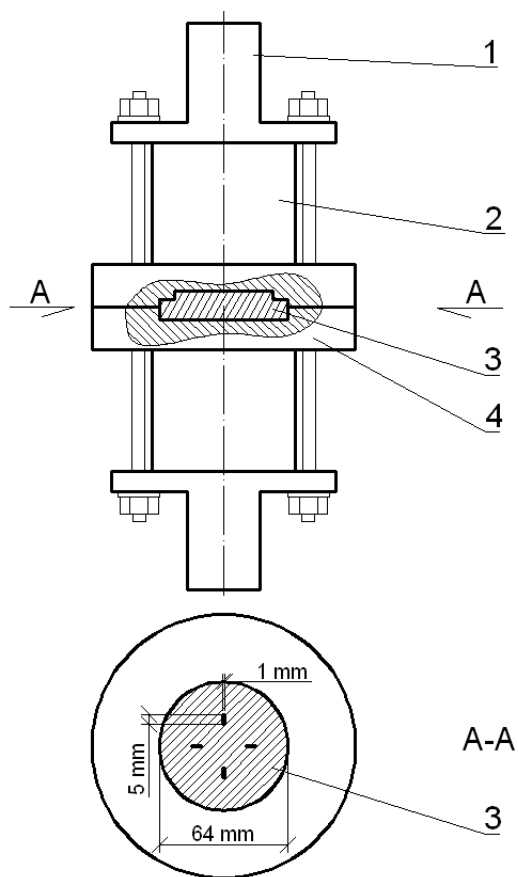


Fig 2. Scheme of cavitation reactor: 1 – steel casing, 2 – acrylic glass pipe, 3 – inductor of the cavitation, 4 – steel plates connecting casing

Samples

The investigated leachate originated from Rokitno landfill, which is located several kilometers from Lublin city, south-eastern Poland. The landfill began its operation in 1994.

Leachate samples were collected to plastic containers, transported to the laboratory and analyzed just after the arrival.

Methodology

The process of hydrodynamic cavitation was carried out for 30 min. Samples were taken at defined time intervals (5, 10, 20 and 30 min) and analyzed for temperature, pH, COD and TOC.

The pH of the samples was determined using an electronic pH meter. The COD of the samples was measured according to Polish Standards PN-ISO 6060:2006. The TOC was measured by an instrumental method with Shimadzu TOC-5050 total organic carbon analyzer. TOC was obtained by the elimination method (TOC = total carbon – inorganic carbon).

3. Results and discussion

The first part of the experiment involved qualitative characterization of leachate. In table 2 the main characteristics of the leachate used in the experiment are shown.

Rokitno landfill is an old storage site and therefore its leachate exhibits relatively low COD values (comparing to these coming from young landfills) as well as low BOD₅/COD ratio.

A few authors (Abbas *et al.* 2009; Kulikowska and Klimiuk 2004) report that the decrease in BOD₅/COD corresponds to the decrease in treatment effectiveness. Barbusiński *et al.* (1997) indicated that during the treatment of leachate from completely stabilized, 50-year old landfill of industrial wastes with the BOD₅/COD ratio of 0.05, the value of COD removal efficiency was 7.5%. Therefore, it is expected that AOPs may be appropriate for the treatment of this kind of leachate.

Table 2. Characteristics of landfill leachate used in the experiment

Parameters	Value
pH	6.7 – 7.6
COD [mg O ₂ /L]	2.4 – 3.2
TOC [mg/L]	750 – 890
BOD ₅ /COD	0.12
TOC/COD	0.24 – 0.35

During the experiment the changes in pH and temperature values were observed. After 30 min of cavitation pH raised from 7.53 to 8.49, and the temperature increased on average by 11 °C. The relation between cavitation time and temperature is presented in Fig. 3. The changes in temperature could be explained by high pressure gradients and extreme increase of the temperature

inside the created and collapsed gas bubbles. The violent collapse of bubbles produces powerful mechanical shear stress. These conditions can lead to the thermal destruction of compounds present in the cavitation bubbles and to the generation of hydroxyl radicals (Neczaj *et al.* 2005).

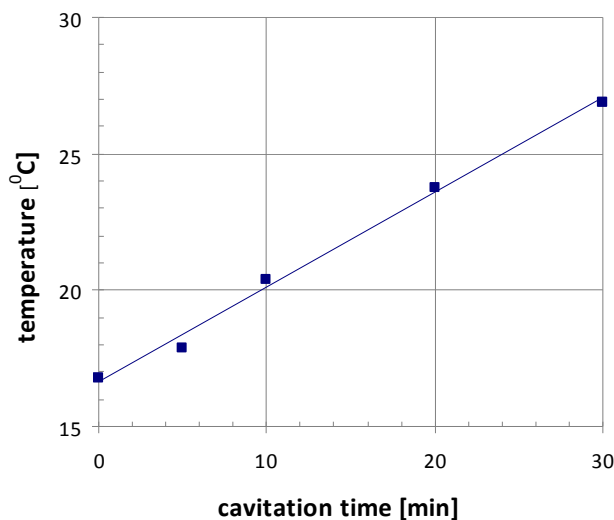


Fig 3. Effect of hydrodynamic cavitation on temperature

In the second part of the experiment the efficiency of COD and TOC removal was examined. Fig. 4 illustrates the decrease in COD and TOC values for the landfill leachate samples in the function of cavitation time. It can be seen that only 6.7% of COD and 5.1% of TOC was removed after 30 min of cavitation.

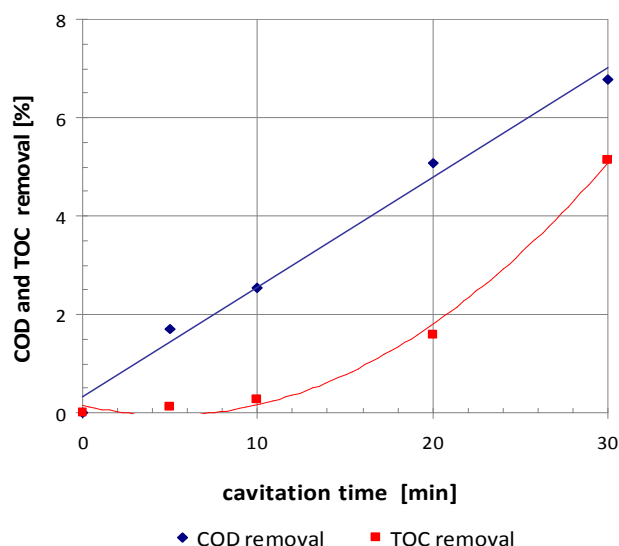


Fig 4. Effect of hydrodynamic cavitation on COD and TOC removal

It is likely that changes in operational conditions such as the cavitation time or the pressure applied would allow to obtain more effective results. In addition, the modification of flow conditions and geometry of the cavi-

tation reactor, particularly the arrangement of holes on the orifice plates, could result in more preferable effects (Sivakumar and Pandit 2002).

The data in the literature indicate that it is very difficult to obtain satisfactory treatment efficiencies by one method alone (Chiang *et al.* 2001; Neczaj *et al.* 2005). Thus, usually a combination of two or three methods is used. It could be possible to enhance the degradation rates by adding various oxidizing agents, like hydrogen peroxide or ozone. Moreover a combination of cavitation with other methods should reduce overall treatment costs, because the operating costs of cavitation include, in fact, only energy consumption (Kurniawan *et al.* 2006).

4. Conclusions

In the article the possibility of landfill leachate treatment by hydrodynamic cavitation was investigated. From the obtained results, it can be concluded that the leachate treatment by this method was not as effective as assumed. Nevertheless the effectiveness of the process could be improved by introducing some changes to the experimental set-up, such as the application of higher pressure or different arrangement of holes on the orifice plates.

Furthermore, it occurred, that the process should not be used as a single step treatment. Combining cavitation with other oxidation processes seems to be more applicable option. Therefore, with the addition of hydrogen peroxide or ozone, it could be possible to enhance treatment efficiency. The feasibility of leachate treatment by hybrid methods appears to be very promising and requires further investigation.

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