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Use of hydrodynamic cavitation in (waste)water treatment

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ABSTRACT

The use of acoustic cavitation for water and wastewater treatment (cleaning) is a well known procedure. Yet, the use of hydrodynamic cavitation as a sole technique or in combination with other techniques such as ultrasound has only recently been suggested and employed.

In the first part of this paper a general overview of techniques that employ hydrodynamic cavitation for cleaning of water and wastewater is presented.

In the second part of the paper the focus is on our own most recent work using hydrodynamic cavitation for removal of pharmaceuticals (clofibric acid, ibuprofen, ketoprofen, naproxen, diclofenac, carbamazepine), toxic cyanobacteria (*Microcystis aeruginosa*), green microalgae (*Chlorella vulgaris*), bacteria (*Legionella pneumophila*) and viruses (Rotavirus) from water and wastewater.

As will be shown, hydrodynamic cavitation, like acoustic, can manifest itself in many different forms each having its own distinctive properties and mechanisms. This was until now neglected, which eventually led to poor performance of the technique. We will show that a different type of hydrodynamic cavitation (different removal mechanism) is required for successful removal of different pollutants.

The path to use hydrodynamic cavitation as a routine water cleaning method is still long, but recent results have already shown great potential for optimisation, which could lead to a low energy tool for water and wastewater cleaning.

1. Introduction

Availability of water is becoming an increasing concern in the globalised world, both in developed and in developing countries. A sustainable use of water sources could result in the search of additional water sources or even in recycling wastewater treatment plant effluents [1]. The goal of biological wastewater treatment is a stepwise oxidation of organic pollutants aiming to achieve complete mineralisation. Yet, numerous wastewater constituents are persistent to biodegradation or they are only subjected to minor structural changes instead of complete transformation into carbon dioxide and water. Alternatively, they may be eliminated by applying advanced abiotic treatment processes such as membrane filtration, UV degradation, ozonation, advanced oxidation processes, one of them being cavitation.

Cavitation, i.e. the appearance of vapour cavities inside an initially homogeneous liquid medium, occurs in very different situations. It can be defined as the breakdown of a liquid medium under very low pressures. This makes cavitation relevant to the field of continuum mechanics and it applies to cases in which the liquid is either static or in motion. When an oscillating pressure field is applied over the free surface of a static or nearly static liquid contained in a reservoir, cavitation bubbles may appear within the liquid bulk if the oscillation amplitude is large enough. This type of cavitation is known as acoustic cavitation. However, cavitation can also occur in a liquid, which is in motion. In liquid flows, this phase change is generally due to local high velocities, which induce low pressures. The liquid medium is then "broken" at one or several points of weakness (gas bubbles, impurities) and larger "voids" (bubble clouds) appear whose shape depends strongly on the structure of the flow. In the developed cavitation, which is the focus of the present study, the flow follows a distinctive pattern where cavitation structures of different shapes and sizes are shed

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from the attached cavity (Fig. 1a) – the flow is from the right to the left.

Developed cavitation occurs when the pressure difference between the outer flow and the inside of the attached cavity, forces the streamlines to curve towards the cavity and the surface beneath it. This causes the attached cavity to close and the formation of a stagnation point at which the flow is split into outer flow which reattaches to the wall and the re-entrant jet which travels upstream, carrying a small quantity of the liquid to the inside the cavity. As the re-entrant jet travels upstream it looses momentum, turns upwards and "cuts" the attached cavity, causing cavitation cloud separation (shedding). The cloud is then entrained downstream by the main flow and can violently collapse in a region of pressure recovery. During the separation, circulation around the structure can appear, causing it to reshape, break up etc. Meanwhile the attached cavity begins to grow and the process is periodically repeated.

As the system pressure is decreased or the flow velocity is increased a small cavity will extend and grow longer and longer. It becomes a supercavity as soon as it ceases to close on the cavitator wall but inside the liquid, downstream of the cavitator (Fig. 1b) – the flow is from the right to the left. Supercavitating flow shows only one quasi steady vapour filled large scale cavity, where larger disturbances in pressure and temperature are uncommon – it is not accompanied by noise, vibration and erosion, which would make the operation of a real facility somewhat easier.

Despite many obvious differences in appearance, on a small scale the principles which govern the hydrodynamic bubble and the acoustic bubble are basically the same. Once the cavitation bubble is generated, it may undergo a violent collapse during which an intense shock wave is emitted. Pressures up to a GPa range and high local temperatures, in the order of 10,000 K can be expected [2]. These conditions are uniquely suited for mechanical substrate surface or membrane cleaning, cell disruption or enhanced oxidation of chemical compounds.

With cavitation one utilises (i) extreme pressures and temperatures from cavitation collapses to disintegrate smaller organic molecules, which are otherwise harder to disintegrate using conventional biological methods and (ii) disintegration of larger particles to enlarge the specific surface and thus increase the rate of hydrolysis and biodegradation of organic pollutants.

Cavitation can be combined with conventional biological treatment using activated sludge. By decreasing the amount of persistent organic pollutants in wastewater treatment plant effluent, we will demonstrate the improved efficiency of treatment.

In the current industrial practice of wastewater treatment hydrodynamic cavitation is not used. Although laboratory experiments exist, the methods have not been routinely applied for practical use – some attempts include [3–6]. This is, in our opinion, mainly due to lack of communication between researchers – the environmentalists concentrate their efforts on ultrasonic cavitation, while the engineers do not realise the usefulness of cavitation and still treat it as a harmful phenomenon.

Hydrodynamic cavitation has the potential to become energy efficient technique that can reduce currently necessary use of expensive chemical reagents for enhanced treatment process, which on the other hand also pose additional concerns when deposited into environment. Cavitation as physical phenomena does not introduce any new chemicals to water and thus does not affect the environment after water is released into environment. Finally, as nowadays a lot of attention is put upon micropollutants such as endocrine disrupting compounds, it is expected that developed process of wastewater treatment with aid of cavitation will considerably reduce their presence in purified water. We expect that cavitation could also be used for disinfection of waste- and drinking water.

Also new applications of hydrodynamic cavitation are beginning to emerge in other fields i.e. decreasing the addition of sulphur in wine production, enhancing bio-gas production from waste activated sludge and homogenisation of pulp in paper production.

Part 1 (Section 2) of the present paper describes a review of methods, techniques and mechanisms, which utilise hydrodynamic cavitation in water and wastewater treatment with focus on pharmaceuticals, bacteria, microalgae and viruses removal.

In Part 2 (Section 3) of the present paper, results of research work performed by our project group during the last three years under the grant of the Slovenian Research Agency are shown. The goal of the research was to investigate the possibility and later energy efficiency of removal of different pollutants from water and wastewater with the final goal to develop an energy efficient industrial scale water and wastewater treatment facility, which would primarily utilise hydrodynamic cavitation for pollutant removal/disintegration.

2. Part 1: a review of methods and mechanisms

This section describes a review of recent applications where hydrodynamic cavitation is used for treatment of water and wastewater with the focus on pharmaceuticals, bacteria, microalgae and viruses removal.

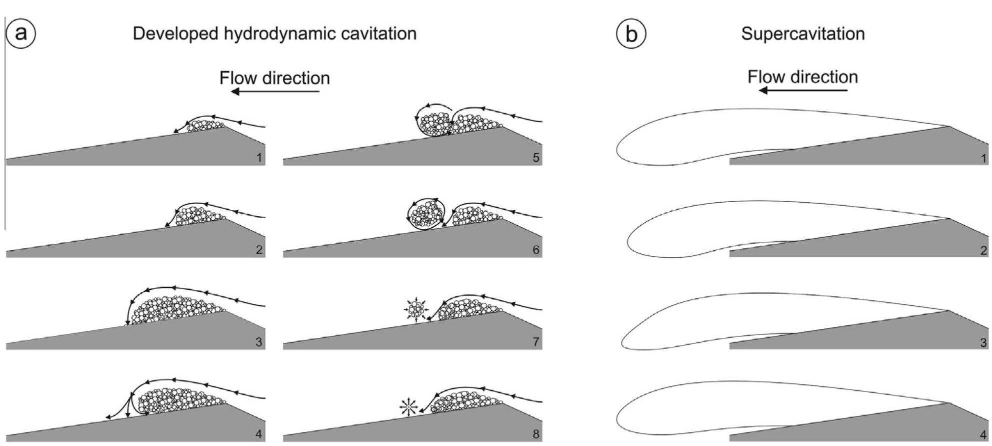

Fig. 1. Schematic representation of "developed hydrodynamic cavitation" (a) where highly dynamical vapour cloud shedding associated with high pressure pulsations is expected and "supercavitation" (b), which is characterised by a single quasi steady large cavitation pocket.