



Daphnia magna filtration efficiency and mobility in laminar to turbulent flows

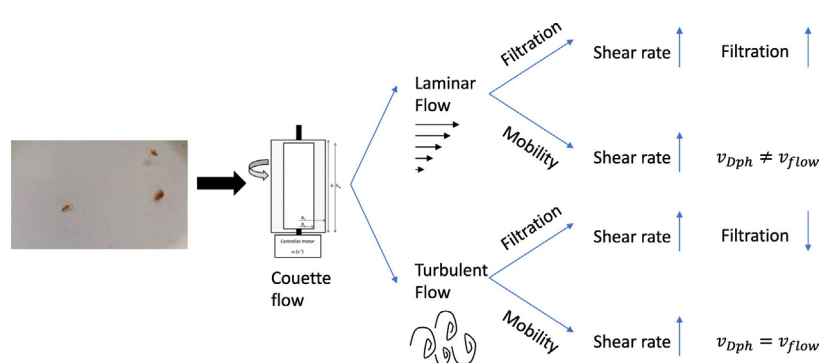
Teresa Serra ^{*}, Aina Barcelona, Marçal Soler, Jordi Colomer

University of Girona, Department of Physics, 17003 Girona, Spain

HIGHLIGHTS

- In the Couette laminar flow the *D. magna* filtration increases linearly with shear.
- Turbulent flow completely inhibits *D. magna* filtration.
- Turbulent regime restricts *D. magna* swimming capacity.
- *D. magna* filtration is predicted to increase with the third power of the body length.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 25 October 2017

Received in revised form 23 November 2017

Accepted 23 November 2017

Available online xxxx

Editor: D. Barceló

Keywords:

Daphnia magna

Filtration

Mobility

Flow regime

Couette flow

ABSTRACT

Daphnia are filter feeder organisms that prey on small particles suspended in the water column. Since *Daphnia* individuals can feed on wastewater particles, they have been recently proposed as potential organisms for tertiary wastewater treatment. However, analysing the effects of hydrodynamics on *Daphnia* individuals has scarcely been studied. This study focuses then, on quantifying the filtration and swimming velocities of *D. magna* individuals under different hydrodynamic conditions. Both *D. magna* filtration and movement responded differently if the flow was laminar or if it was turbulent. In a laminar-dominated flow regime *Daphnia* filtration was enhanced up to 2.6 times that of a steady flow, but in the turbulent-dominated flow regime *D. magna* filtration was inhibited. In the laminar flow regime *D. magna* individuals moved freely in all directions, whereas in the turbulent flow regime they were driven by the streamlines of the flow. A model based on *Daphnia*-particle encountering revealed that the filtration efficiency in the laminar regime was driven by the length of the *D. magna* individuals and the shear rate imposed by the system.

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1. Introduction

The cladoceran *Daphnia magna* is an organism found in many aquatic systems. It is known to feed on phytoplankton as well as on bacteria, and is responsible for what it is known as the clear water phase of a lake

(Burns, 1969a, 1969b; Shiny et al., 2005; Berger et al., 2006; Pau et al., 2013; Lamonica et al., 2016). *Daphnia* individuals can also feed on wastewater particles, which mean that a population of *D. magna* can be used as a tertiary treatment to generate water for reuse (Serra et al., 2014). This hypothesis is based on the fact that individuals of *D. magna* provide inactivation levels of 1.4 log units of *E. coli* from wastewater and can reduce turbidity by as much as 60–70% (Serra et al., 2014; Shiny et al., 2005). A population of *D. magna* has also been proved

^{*} Corresponding author.

E-mail address: Teresa.serra@udg.edu (T. Serra).

to remove emerging contaminants from wastewater (García-Rodríguez et al., 2014; Matamoros et al., 2012; Matamoros and Bayona, 2013) and to be sensitive to several products, which is why it is a model organism largely used in ecotoxicology (Garreta-Lara et al., 2018).

There are many studies that demonstrate that *Daphnia* individuals reduce their activity when subjected to unfavourable environmental conditions (Gorski and Dodson, 1996; Maceda-Veiga et al., 2015; Chen et al., 2015; Pan et al., 2017). *Daphnia* individuals have been found to exhibit disorders in filter feeding activity, swimming speeds and trajectories, growth, heartbeat, metabolism and survival when exposed to unfavourable factors (Bownik, 2017; Garreta-Lara et al., 2018). Individual unfavourable factors are: high and low temperatures (Berger et al., 2006; Schalau et al., 2008; Serra et al., 2014), high salinities (Bezirci et al., 2012; Liu and Steiner, 2017), high concentrations of chemicals and pharmaceuticals (Pan et al., 2017; Santojanni et al., 2003) and the presence of microplastics (Rehse et al., 2016). A combination of factors such as salinity, temperature and hypoxia has also been proved to negatively affect *D. magna* individuals (Garreta-Lara et al., 2018). For example, temperatures above 26 °C coupled with nitrate concentrations above 250 mg l⁻¹ produced a 60% mortality in a population of *D. magna* (Maceda-Veiga et al., 2015). The presence of nitrite increased the mortality of *D. obtusa*, delayed the time to the first batch of eggs and reduced the number of moulting and clutches, especially for nitrite concentrations above 2 mg l⁻¹ (Xiang et al., 2012). A change in temperature from 5 °C to 25 °C induced *D. pulex* individuals to modify trails and sedimentary velocity, and the decrease in the settling velocity was also attributed to the increase in temperature (Gorski and Dodson, 1996). An increase in water temperature from 12 °C to 22 °C resulted in an increase in the swimming speed of *D. pulex* individuals, thus making them more vulnerable to predators (vulnerability increases from 83% to 121%) as a result of the higher encountering rates between predator and prey (Riessen, 2015). Therefore, the analysis of abiotic parameters in controlled conditions is considered a systematic approach to evaluating *D. magna* performance in stressful environments.

Despite all the studies on how individual factors or combinations of them affect *D. magna* performance, how the flow environment affects their filtration rate is hardly known and is a crucial element when determining the flow rate in any reactor designed to treat water based on *D. magna* filtration. Hydrodynamics might impose some limitations to the normal functioning of Cladocera. An increase in *Daphnia* swimming speed along more tortuous paths, resulting from the chaotic movement of the flow, occurred after turbulence was increased using an oscillating grid (Seuront et al., 2004). The increase in the flow rate due to a reduction in the hydraulic residence time in a wastewater treatment system, impacted the capacity of *D. magna* filtration (Serra and Colomer, 2016). Residence times of 3 h produced high flow velocities and diminished the filtration efficiencies of *D. magna* individuals to 2%, while residence times over 12 h, corresponding to lower flow velocities, increased the filtration efficiencies by over 30%.

In this study, we analyse the behaviour of *D. magna* in a set of experiments encompassing both laminar and turbulent hydrodynamics. The hydrodynamics were generated with a Couette flow system. A Couette flow device is a system composed of two concentric cylinders. When these cylinders rotate, they produce a shear flow in the space between the cylinders, which is a well-known function of their rotating velocities. A Couette flow device also enables a steady controlled flow to be produced (Shimeta et al., 1995) that could encompass a gradual transition from laminar to turbulent conditions (Serra et al., 1997, 2008). This system has been proved to be useful for a number of hydrodynamic purposes such as aggregating and breaking up particles (Serra et al., 1997; Zhu et al., 2016) or studying the influence turbulence has on protozoa feeding (Shimeta et al., 1995).

A total of 34 runs were designed to determine the favourable hydrodynamic flow environment for *D. magna* performance. Filtration capacity and swimming speed are non-intrusive methods and were used as the main parameters to study the responses of *D. magna* individuals to

the hydrodynamics of the flow. *Daphnia* swimming behaviour is one of the most sensitive biomarkers in toxicity experiments (Bownik, 2017), while filtration capacity is an indicator of the performance of *D. magna* individuals under variable factors such as water temperature and food availability (Pau et al., 2013; Serra et al., 2014).

2. Materials and methods

2.1. Couette flow

The flow field was generated by a Couette flow device entailing two concentric cylinders (Fig. 1). The inner cylinder had a radius of $r_1 = 2.5$ cm and the radius of the outer cylinder was $r_2 = 4.5$ cm, i.e. the gap ($r_2 - r_1$) was 2 cm wide. The height of the cylinders was $h = 15.5$ cm. The outer cylinder rotated at an angular velocity that ranged from $\omega_2 = 0$ rad s⁻¹ to 7.39 rad s⁻¹ (see Table 1) and the inner cylinder remained at rest ($\omega_1 = 0$ rad s⁻¹). The space between cylinders was filled up to $h_w = 13.64$ cm. Therefore, the volume of water within the cylinders was 600 ml. The flow velocity in a Couette flow device can be calculated according to Kundu and Cohen (2002),

$$v = ar + \frac{b}{r} \quad (1)$$

where a and b are coefficients that depend on both the radius and the angular velocity of the cylinders and r is any position along the radial axis situated within the gap between cylinders, i.e.

$$a = \frac{\omega_1 r_1^2 - \omega_2 r_2^2}{r_1^2 - r_2^2} \text{ and } b = \frac{\omega_2 r_1^2 r_2^2}{r_1^2 - r_2^2} \quad (2)$$

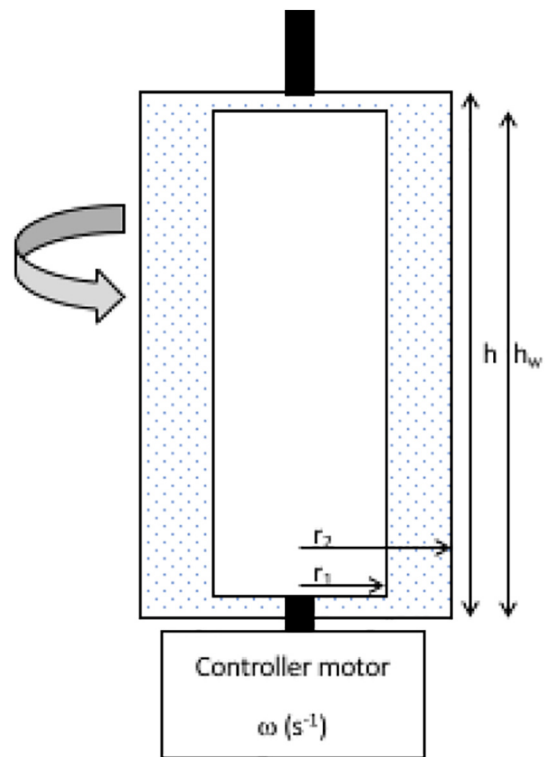


Fig. 1. Scheme of the experimental set-up of the Couette flow device. r_1 is the radius of the inner cylinder, r_2 is the radius of the outer cylinder, $r_2 - r_1$ is the gap width between cylinders, h is the height of the outer cylinder and h_w is the water height. ω is the angular velocity of the outer cylinder.

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