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Release of suspension particles from a prismatic tank by multiple jet arrangements

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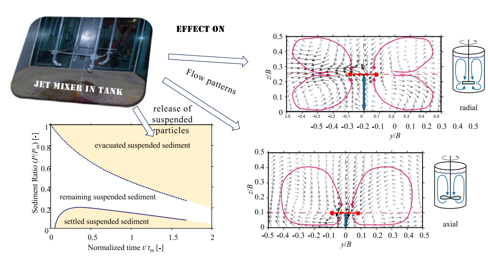
HIGHLIGHTS

- A circular jet arrangement for mixing near the bottom of a tank is proposed.
- The arrangement can resuspend and keep in suspension particles.
- Efficient release of suspended particles trough the tank outlet is achieved.
- The findings can be used for designing sediment evacuation devices in reservoirs.

GRAPHICAL ABSTRACT



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ABSTRACT

The performance of circular and linear jet arrangements on the release of suspended sediment out of a prismatic tank has been investigated. Experiments conducted are (1) without any forced jet stirring (reference case), (2) four jets arranged in a horizontal circle and (3) aligned jets; they were all in a tank containing water with a known homogeneous initial suspended sediment concentration. The concentration of the suspended sediment inside the tank and released through the outlet is monitored over time, and the evacuated sediment ratio (ESR) is defined, computed, and used as a metric for comparison between the various configurations. The idealized suspended sediment release is also calculated and compared to measured quantity. In order to explain the significant differences in evacuated sediment ratio, the induced circulation is analyzed by measuring the flow field on two vertical planes using the ultrasonic Doppler method. The geometrical parameters of the jet arrangement, the outlet elevation as well as the discharge of the jets are varied. Thus, the optimal parameter combination regarding sediment release can be identified. Finally, recommendations regarding jet arrangement and jet discharge practice in conditions of high sediment release are given.

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1. Introduction

The purpose of the present study is to release a suspended sediment load as high as possible out of a rectangular tank having a quasi-homogeneous sediment-water mixture as an initial condition, achieved by water jets working as a mixer. Specific jet arrangements provide the energy and generate the optimal circulation needed to maintain the sediment in suspension and enhance its entrainment into the outlet placed on the front wall. Circular and linear jet arrangements were tested in order to find

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the optimal jet configuration regarding sediment release. As the linear jet arrangement was found to be much less favourable in view of sediment release, in the same magnitude as for the experiments without any jets, its behaviour has not been investigated further.

Jet mixing with a single jet and jets linearly aligned and its influence on mixing time have been studied before for a vast variety of conditions.

Mixing was reported to be either directly proportional to the circulation time (Grenville and Tilton, 1996) or to the square root of the tank height multiplied by the tank diameter (Fox and Gex 1956; Lane and Rice 1982). In the mixing time correlations of Fossett and Prosser (1949), Fossett (1951), and Grenville and Tilton (1996), cited by Wasewar (2006) mixing time is inversely proportional to the square root of the jet momentum flux, whereas Fox and Gex (1956) and Lane and Rice (1982) promote inverse proportionality to two-third of the same square root. Stefan and Gu (1992) found that low momentum jets are more energy-efficient than high momentum jets, while Ranade (1996) found that mixing time was directly correlated to the jet momentum. According to Coldrey (1978) and Perona et al. (1998) for constant jet flow rate, mixing time is directly proportional to jet diameter. From the experiments of Patwardhan and Gaikwad (2003) results that at the same power consumption level, an increase in diameter will lead to a decrease in mixing time.

According to Maruyama et al. (1982, 1984), Patwardhan and Gaikwad (2003), Grenville and Tilton (1996) mixing time depends strongly on the jet angle, while Okita and Oyama (1963) suggest that the jet angle does not affect mixing time. Mewes and Renz (1991) and Perona et al. (1998) as well as Maruyama et al. (1982, 1984) and Maruyama (1986) found that the position of the nozzle is one of the parameters affecting the mixing process. Zughbi (2006) concluded after a re-analysis of the experiments of Perona et al. (1998) with the help of CFD simulations that the jet location is very important in determining mixing time. Zughbi and Rakib (2004) show from their experiments that for a given geometric arrangement, the angle of injection is significantly more important than the length of jets. Ranade (1996), Zughbi and Rakib (2004), Jayanti (2001) as well as Zughbi (2006) all highlight the importance of flow patterns on mixing. Revill (1992) considered that mixing time is proportional to the circulation time, defined as ratio of the fluid volume V to the jet flow rate Q_j, giving the hereafter-used mean residence time τ_m. It can be seen from literature, that there is no general consent on the influence of the main parameters involved.

Binnie and Hookings (1948) investigated vortex type circulation where water in a tank acquired an induced swirl by a combination of radial and tangential jets. Posey and Hsu (1950) chose the same approach; they used both radial and tangential jets with 1-inch nozzles to generate various degrees of circulation in an 8-feet cylindrical tank. Both studies were not designed for mixing, but for vortex flows.

In the present study, a circular jet arrangement that has not been analysed systematically earlier, turned out to perform well. It generates a flow field similar to that of a classical mechanical impeller whose influence on suspension had been systematically investigated by Zwietering (1958) and Sharma and Shaikh (2003) in rather small containers.

In the present study the impact of several geometrical arrangements, water outlet elevation and jet discharge on flow pattern and sediment release were experimentally investigated. Turbidity within the tank and in the outflowing water was measured with turbidity probes and the flow velocity field with the ultrasonic velocity profiling (UVP) technique. This provided information about the suspension and sediment release efficiency.

2. Experimental set-up and parameters

2.1. Description of the experimental facility

The physical experiments were carried out in a prismatic tank with vertical glass walls. The tank has an elongated rectangular shape with a total inner basin length L_{tot}=4 m, an inner width of B=1.97 m and a total inner basin height of H=1.50 m (Fig. 1a). The main tank, where the experiments were conducted, has a length of L=3.5 m. In the middle of the front wall, a vertical PVC plate is located, where the water outlet can be inserted at three different

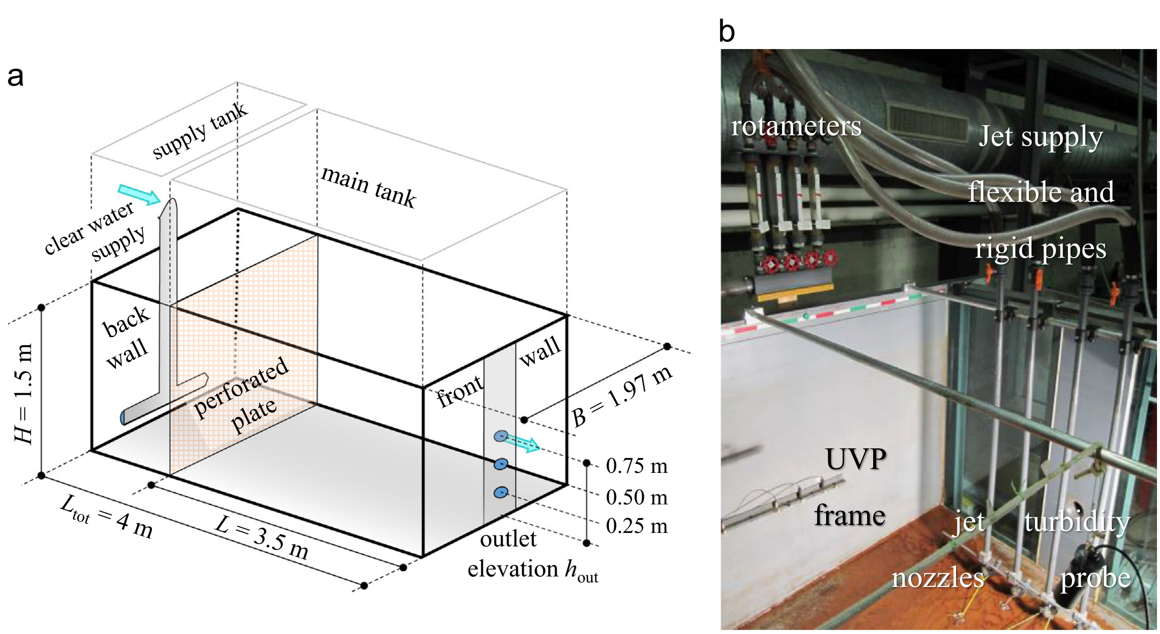

Fig. 1. (a) Schematic view of the experimental installation; (b) picture of the tank with the four rotameters leading the water into flexible pipes and to the rigid pipes and down to the nozzles (in the picture linear jet configuration). The main tank turbidity probe hangs on a rope in the tank (right lower corner).

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