Characterization of Thruster-Induced Turbulence for Fine Sediment Suspension

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Reservoir sedimentation is a key challenge for storage sustainability because it causes volume loss, affecting hydropower production capacity, dam safety, and flood management. A preliminary EPFL study proposed and studied an innovative device (called SEDMIX), which uses water jets to keep fine sediments near the dam in suspension and ultimately allows the sediments to be released downstream. The jets induce a rotational flow which creates an upward motion and keeps fine sediments in suspension near the dam and water intakes. The sediment can then be continuously released downstream through the power waterways at acceptable concentrations, without additional water loss or required energy. The efficiency of the SEDMIX device has been confirmed through experimental simulations and numerical analyses at EPFL This study involves updated experimental simulations to include thrusters in the device design instead of water jets, because they lead to a less complex arrangement that requires less energy to operate. The thruster-induced turbulent kinetic energy is observed and characterized using Ultrasonic Velocity Profiling (UVP) to determine optimal device configurations for effective sediment release.

Keywords: reservoir sedimentation, storage losses, sediment routing, turbidity currents, dam safety, sediment suspension, thrusters, hydrodynamics, long range Ultrasonic Velocity Profiling (UVP), turbulence, Met-Flow

1. Introduction

1.1 Scientific Background

In high-altitude alpine reservoirs, turbidity currents are the main inflow process for sediments [1]. Turbidity currents mainly occur during floods, when a sediment-laden river enters the reservoir downstream of the root delta. These currents transport fine sediments downstream to the deepest part of the reservoir, close to the dam. This causes two main issues: increased sedimentation at the dam (decreasing the available storage volume for hydropower and flood control), as well as negatively impacting operation of the bottom outlets and/or water intakes.

Reservoir sedimentation is a key challenge for storage sustainability because it causes volume loss, affecting hydropower production capacity, dam safety, and flood management. According to a recent UN University study [2], it is forecasted that dams around the world will lose nearly a quarter of their storage capacity due to sedimentation by 2050. This storage loss rate is of particular concern for mid-altitude reservoirs which must regularly conduct costly sediment management operations which affect their sustainability. The SEDMIX device is designed to help solve this exact issue: minimizing the ongoing sedimentation issues in existing dams.

1.2 Existing Technologies

To combat reservoir sedimentation and the negative impacts of turbidity currents, there are several sediment management strategies that are being investigated and applied worldwide. These include venting, flushing, and mechanical dredging, among others. While these strategies have benefits, they also have practical challenges that hamper using them as successful techniques [3].

For example, venting allows for the release of sediments downstream during a flood event but requires a substantial amount of water release in the process (decreasing hydropower availability and production). Mechanical dredging allows for removal of large quantities of deposited sediment but is costly and requires ongoing maintenance and disposal of the dredged material. Flushing is more cost effective but may require powerplant outage for a limited period and may have larger potential for adverse downstream impacts.

This study focuses on an innovative concept for a system that does not have as many negative aspects when it comes to dam-reservoir operation. The SEDMIX device is a more flexible and versatile solution that has the potential to be employed in reservoirs with a diverse range of design details and location-specific criteria than each of the solutions mentioned above.

1.3 SEDMIX Device Concept

A PhD thesis that was completed at EPFL PL-LCH [4] proposed and lab-tested an innovative system (called SEDMIX), which used water jets to keep fine sediments near the dam in suspension and allowed them to be routed downstream. This study involves updated experimental simulations to include thrusters in the device design, instead of jets, because it leads to a less complex arrangement that requires less energy to operate.

The thrusters induce a rotational flow which creates an upward motion. This thruster arrangement is beneficial for sediment release as it keeps fine sediments in suspension near the dam and water intakes. The sediment can then be continuously routed downstream through the power waterways at suitable concentrations, without additional water or energy loss.

The SEDMIX device consists of two rigid parts: one floating at water level and one on the basin bottom holding a multi-thruster manifold frame (shown in Figure 1). Once constructed, the thruster manifold frame will be suspended from a floating platform and lowered underwater into position. As such, the system can be mobile and can be moved around the reservoir to find the position that provides optimal sediment evacuation. The facility is modular and combines the use of different materials, taking into consideration structural resistance, weight, workability, aging properties, and cost.

Figure 1: Conceptual graphic showing SEDMIX design (source: PL-LCH)

2. Experimental Setup

This study involves a physical experimental model to study thruster performance and the ability of the SEDMIX device to keep fine sediments in suspension. The goal of the study is to better understand the influence of the SEDMIX device on reservoir hydrodynamics. The experimental setup is shown in Figure 2 and described in the following sub-sections.

The experimental setup allows for testing different thruster configurations and parameters, including the number, size, location, and angle of the thrusters. Three ultrasound transducers are used to measure vertical velocity profiles in the water column (Figure 2). At steady state, the locations of the transducers (and therefore the measured profiles) are systematically moved using a robotic transversal system to ultimately develop a two-dimensional grid of velocity profiles and calculated turbulence.

2.1 Laboratory Tank

The physical experiments are conducted in a prismatic tank with vertical walls. The tank has an inner basin length of 4.0 meters (m), an inner width of 1.97 m and a basin height of 1.50 m (for a total volume of 11.8 m^3). The bottom of the tank is a steel plate. Most of the front and right lateral walls are made of glass, providing transparency for visual observations, and the other walls are made from steel plates.

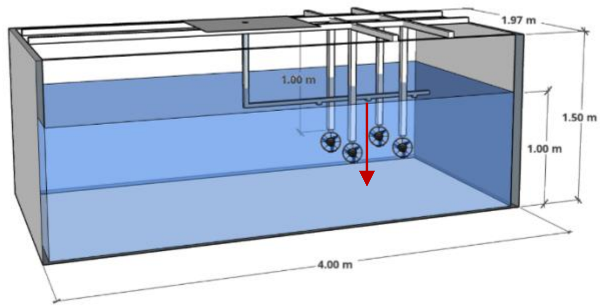

Figure 2: Experimental Setup (source: PL-LCH). Red line shows the direction of the UVP measurement.

2.2 Thrusters

This study involves the use of four thrusters, set up in a grid as shown in Figure 3.

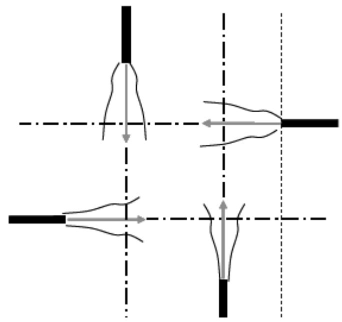

Figure 1: Plan view of thruster geometry (source: PL-LCH)

The thrusters used for this experiment are Blue Robotics T200 thrusters [5], which consist of a fully flooded brushless motor with encapsulated motor windings and stator as well as coated magnets and rotor (see Figure 4). The thruster body and propeller are made from polycarbonate plastic and the only exposed metal components are made from marine grade 316 stainless steel.

Based on information from the manufacturer, the thrusters have a (approximate and theoretical) maximum velocity output of 4.5 m/s, and a maximum discharge of 0.0125 m3/s. The thrusters are supported with a movable steel frame, as shown in Figure 2.

The thrusters can generate thrust both in the forward and reverse directions, although the reverse direction has a lower force and efficiency. The thruster throttle can be controlled using a programmed electronic speed controller (ESC), which then uses a Pulse Width Modulation (PWM) signal to control the throttle of the thruster.

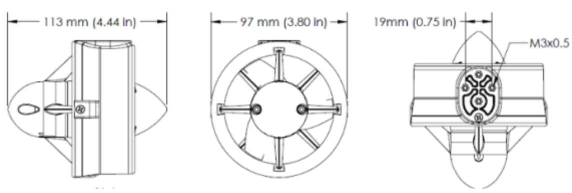

Figure 4: Thruster T 200 Schematic (source: Blue Robotics)

2.3 Long-range Ultrasonic Velocity Profiling (UVP) transducers

Met-Flow long range Ultrasonic Velocity Profiling (UVP) transducers (2 MHz) are used to study induced velocities in the tank, as ultimately, turbulent kinetic energy.

The Ultrasonic Velocity Profiling technique (UVP), using the UVP DUO profiler by Met-Flow, measures instantaneous velocity profiles of liquid flows by using the Doppler shift of echoes reflected by small particles flowing with the liquid. The UVP technique is quasi non-intrusive and hence, does not disturb the flow circulation.

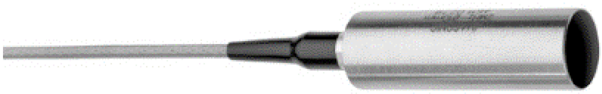

Figure 5: Ultrasound Transducer (image provided by Met-Flow)

For this experiment, the transducers are mounted to a horizontal rod at the top of the water column and are pointed downward to obtain velocity profiles (see Figure 2). The transducer locations are easily changed because they are mounted using a robotic arm that is remotely controlled, allowing for measurements at known and precise locations.

Table 1 outlines the parameters used to take measurements using Met-Flow software and the UVP DUO profiler.

Table 1: Summary of Ultrasonic Doppler Velocity Profiler Measurement Parameters

Parameter	Value
Ultrasonic Frequency	2 *MHz*
Transducer Diameter	24 *mm*
Number of Cycles	4
Channel Width	1.48 *mm*
Number of Repetitions	128
Sound Velocity	1480 *m/s*
Output Voltage	90 *V*
Number of Samples	1024

3. Methodology

The focus of this experiment is to test the influence of different thruster and geometric configurations on the hydrodynamics in the experimental tank. Variables that were tested during this study include:

- the location of the thrusters (distance between each thruster and off-bottom clearance),
- the angle of the thrusters (with respect to horizontal), and
- thrust output of each thruster (RPM).

The tank is a closed system that does not have any incoming or outgoing flow. The water height is kept constant at a depth of 1.0 m. The temperature of the water was kept at room temperature (between 15 - 20°C), and as such, the viscosity does not vary significantly. The experiments are conducted without specific particle tracers, instead using natural impurities present in the water for echoes (dust, organic material, etc.).

3.1 Geometric Parameters

Figure 6 outlines the geometrical parameters of the tank and thruster system.

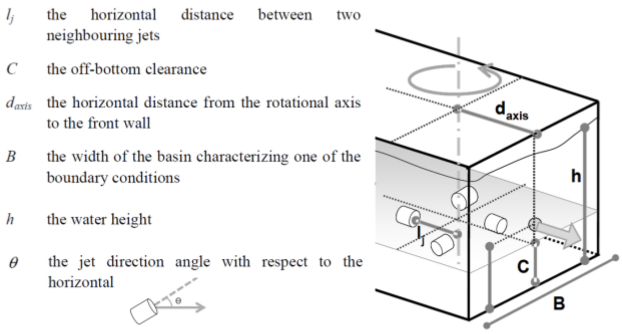

Figure 6: Geometrical parameters regarding the thruster and tank configuration (adapted from [4])

3.2 Experimental Parameters and Configurations

Table 2 outlines the different experimental configurations that are performed for this study, starting with the control (which was adapted from the optimized configuration found in [4]). The subsequent experiments then test one variable at a time, keeping all other variables constant (and equal to the control case).

Table 2: Experimental Parameters and Configurations (see Figure 6 for parameter descriptions)

Experiment	Thrust *[RPM]*	l_j *[m]*	C *[m]*	Θ *[°]*
Control	1550	0.5	0.5	0
1a	1530	0.5	0.5	0
1b	1570	0.5	0.5	0
1c	1600	0.5	0.5	0
2a	1550	0.4	0.5	0
2b	1550	0.6	0.5	0
2c	1550	0.7	0.5	0
3a	1550	0.5	0.4	0
3b	1550	0.5	0.6	0
3c	1550	0.5	0.7	0
4a	1550	0.5	0.5	+ 45
4b	1550	0.5	0.5	– 45

4. Results

The first measurement that is considered for each of the different experimental configurations is the water velocity profiles and the maximum velocity observed. Figure 7 shows an example of a velocity profile measured using the transducers and UVP DUO by Met-Flow (see orientation of transducer in Figure 2). The use of three transducers, pointed in the downward direction, will allow for the characterization and quantification of velocity in the water column in a vertical plane.

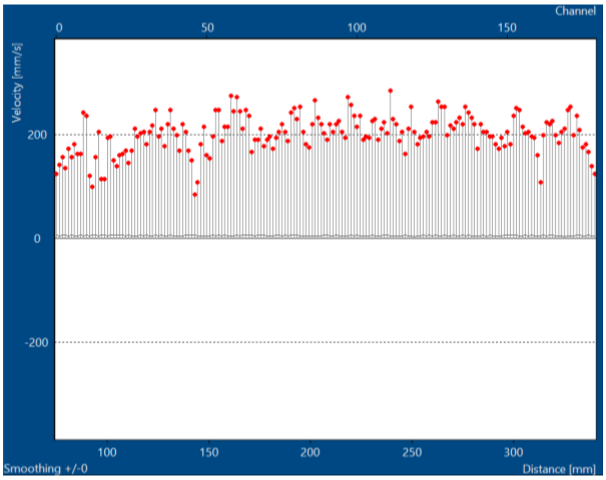

Figure 7: Preliminary UVP results for Experimental Configuration 1a measuring the velocity profile in the water column (Met-Flow UVP Software Version 3)

Using information from the velocity profiles obtained during the different experimental configurations, turbulent kinetic energy is calculated. The optimal geometric configuration will be one that results in inducing the magnitude of turbulent kinetic energy that keeps fine sediment in suspension. Mean kinetic energy, which represents the quantitative measure of the intensity of turbulence and the fluctuation in flow velocity, will be calculated using the velocity profile information obtained from the UVP analysis and characterized and compared in different zones of the measured cross-section.

Calculation of the turbulent kinetic energy for the experimental configurations outlined in Table 2 will allow for the determination of the optimal geometric and operational parameters that result in flow conditions that maximize sediment suspension. In a real reservoir, these flow characteristics would then lead to optimal sediment release downstream.

5. Ongoing research

In parallel to this study, numerical simulations of this experimetnal setup are also being performed in order to compare results to the physical experiment, validate the measurements from the ultrasonic transducers, and test additional configuration and parameter combinations.

Ultimately, the results obtained from this study will aid in the next step of the project, which is prototype implementation of a SEDMIX device in a reservoir for further testing and observation in real, full-scale conditions. The experimentally established UVP transducer configuration for measuring velocities, flow patterns, and ultimately device efficiency, will be used to define locations of field measurements using UVP. Information gleaned from these studies will allow for continued optimization of the device and industrial development for use in reservoirs that have fine sedimentation issues.

6. Acknowledgements

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