6th Micro and Nano Flows Conference
Atlanta,USA, 9-12 September 2018

An Optimization Study on Thermal Energy Harvesting from Micro Cavitating Flows

Morteza GHORBANI [1,2] , LUIS G. VILLANUEVA [3], Ali KOSAR [1,4,*]

* Corresponding author: Tel.: +90 (216) 483 9621; Fax: +90 (216) 483 9550; Email: kosara@sabanciuniv.edu
1. Department of Medical Engineering, School of Technology and Health, KTH Royal Institute of Technology, Stockholm, Sweden
2. Mechatronics Engineering Program, Faculty of Engineering and Natural Science, Sabanci University, 34956 Tuzla, Istanbul, Turkey
3. Department of Mechanical Engineering, École Polytechnique Fedérale de Lausanne, Lausanne CH-1015, Switzerland
4. Center of Excellence for Functional Surfaces and Interfaces for Nano-Diagnostics (EFSUN), Sabanci University, Orhanli, 34956 Tuzla, Istanbul, Turkey

Keywords: Micro Scale Cavitation, Energy Harvesting, Bubble Collapse

In this study, energy harvesting from micro cavitating flows exposed to a targeted thin plate was investigated. Hydrodynamic cavitation occurs when the local static pressure is reduced to a critical value along the flow. The generated cavitation bubbles travels to the outlet of the microchannel and collapse once the pressure increases downstream of their originating position. When sufficiently many cavitation bubbles collapse, they release high energy downstream of the flow channel, which can act as a uniform heat source on the targeted plate. It was demonstrated in our previous study [1] that the energy released from the collapse of cavitation bubbles could be harvested when micro scale cavitating flows interacted with a solid body as a targeted area and could be utilized to provide the required power for the daily used miniature devices The aim of this study is to determine, under which conditions maximum energy can be harvested. The distance between the tip of the microchannel and the targeted plate is the key parameter in this study. For this, experiments at various pressure values and distances between the cavitating jet and the target plate were conducted.

The collapse of hydrodynamic cavitation bubbles leads to high energy dissipation and highly localized and large-amplitude shock waves and high velocity jets [2,3]. In some studies, temperatures over 1000 K and microjets reaching 300 m/s velocities have been reported as a result of the collapse of cavitation bubbles.[4,5] High speed jets allow effective heat transfer, therefore, they can be used in cooling applications as sprays over targeted areas. However, it was also proven that as a result of the exposure of cavitation bubbles to a surface, it is possible to obtain a temperature rise on the surface of the target. Therefore, a sufficient intensity of small cavitation bubbles could serve for generating a heat source with a uniform temperature distribution on the targeted area, which can be used in thermoelectric generators to power daily life devices.

The cavitating-flow generation setup used in this study is shown in Figure 1. A high-pressure pure nitrogen tank (Linde Gas, Gebze, Kocaeli, Turkey) supplies the required upstream pressure for the system. This tank is connected to a 1 gal fluid reservoir (Swagelok, Erbusco BS, Italy), which is filled with deionized water and serves as the working fluid. The reservoir is connected to the system with adapter fittings. Two pressure sensors (Omega) are mounted at the entrance and end of the tubing system to measure the pressures. Two fine control valves (Swagelok) are integrated to the system to control the flow at the desired locations. A micro T-type filter (Swagelok) with nominal pore size of 15 µm is used to filter any particles larger than 15 µm.

An aluminum plate with a surface of 1 × 1 cm^2 and weight of 1.85 g is kept at different distances from the tip of the microchannel to act as the exposed surface for impingement of the cavitating flow resulting from microchannel. The depth of the aluminum plate utilized in this study was 1 mm. The area, which was accordingly chosen to calculate the effect of temperature rise, was 4π mm^2. The

Figure 1. *Schematic of the Proposed System for Generating Cavitation Bubbles and Micro Cavitating Flows*

experiments were performed in microchannel with an inner diameter of 504 µm, since cavitating flows generated in this channel configuration had the highest temperature rise on the surface of the plate as a result of the interaction between the cavitiang jet and the target according to our previous study. In the presence of intense cavitating flows downstream of the cavitating-flow generator device (microchannel acts as a restrictive element connected to the stainless steel tube), a heating effect can be accomplished. The temperatures were recorded using a thermal camera system at different upstream pressures from 10 to 60 bars, while the downstream pressure was fixed at atmospheric pressure. The temperatures were measured at various distances between the nozzle and the target, namely 2, 10, 20 and 30 mm for all the cases of the pressure differences.

The thermal camera results shown in figures 1 and 2 correspond to the 2 and 30 mm distance cases from the tip of the nozzle. The results are displayed for upstream pressures of 10, 20, 40 and 60 bars at the time of the exposure and 30 seconds after the exposure of the cavitating flow for the distance of 2 mm in Figure 1 and the distance of 30 mm in Figure 2. The overall results indicate an increasing trend when the exposure lasts at 30 seconds after the exposure for all of the cases at different distances.

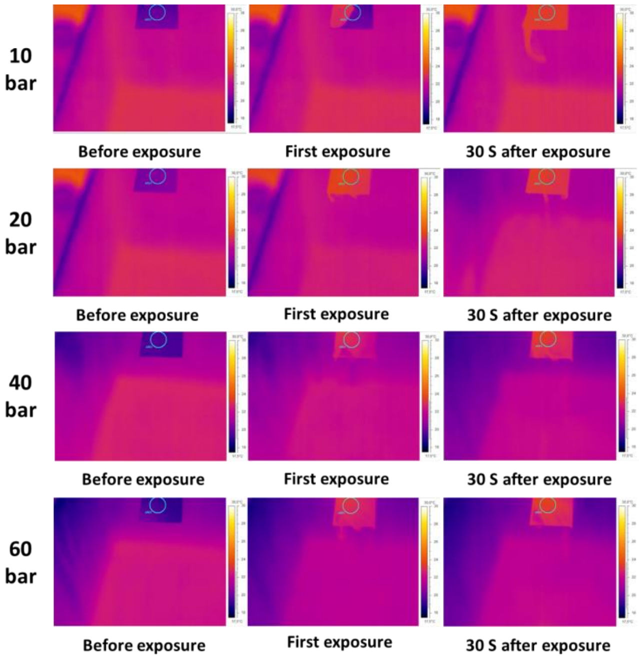

Figure 2. *The temperature distribution on the targeted plate at the distance of 2 mm from the tip of the nozzle (acquired by the FLIR Thermal camera*

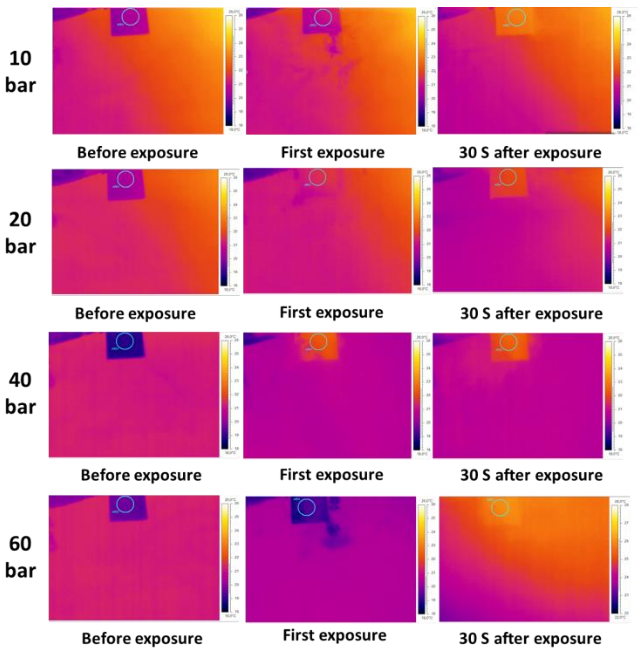

Figure 3. *The temperature distribution on the targeted plate at the distance of 30 mm from the tip of the nozzle*

The data reduction from Figures 2 and 3 are presented in Figures 4 and 5, where the temperature rise for all the cases are gathered for different upstream pressures and distances at the time of the exposure and 30 minutes after the exposure. The results indicate that at the lower distances from the tip of the nozzle the temperature difference raises to 4 degrees approximately for almost all the upstream pressures. The highest temperature rises are achieved at the highest upstream pressure for all the distance cases, while the maximum temperature was recorded at the distance of the 30 mm from the tip of the nozzle at upstream pressure of 60 bar.

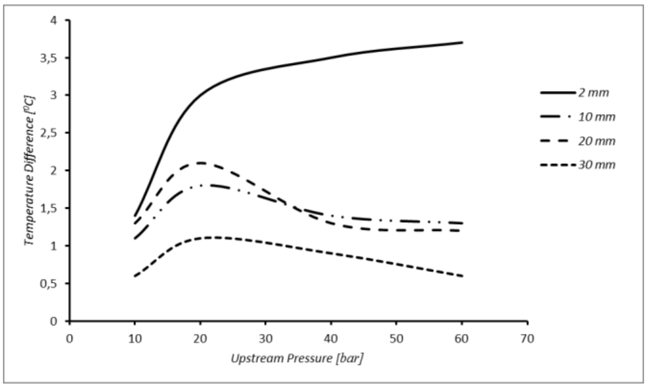

Figure 4. *Surface temperature rise as a function of upstream pressure for different distance cases at the time of cavitating flow exposure to the target*

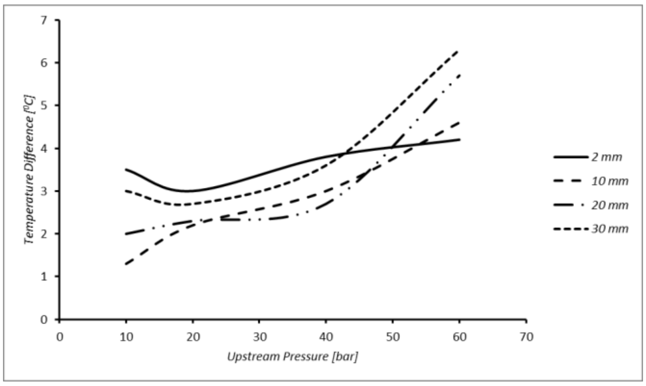

Figure 5. *Surface temperature rise as a function of upstream pressure for different distance cases 30 seconds after cavitating flow exposure to the target*

This study proves that the temperature rise on the surface of the targeted plate depends on both upstream pressure and distance from the nozzle. The variations in temperature rise are different depending on the distance as well as the pressure.

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