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Characterization of a Sub-Atmospheric Pressure-Inducing Micropump Based on Flow Rate and Gauge Pressure Measurements

The pumping mechanism in multi-inlet microfluidic channels usually requires multiple micropumps to be separately attached to each inlet. Unfortunately, this may create fluid leakage resulting from a considerably high internal pressure. To address this, a passive sub-atmospheric pressure-inducing micropump is proposed and its performance is characterized as a function of the flow rate and the gauge pressure. With this pump, a sufficiently high flow rate is generated, comparable to some active-piezoelectric micropumps. The gauge pressure is exponentially descending with time and can be crudely classified into three regions of high, moderate, and slow pressure-release times. Overall, the stabilized pressure is identified within $70\,s < t \leq 300\,s$ for slow rate mixing while rapid mixing is applicable at $t \leq 70\,s$.

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1 Introduction

Point-of-care (POC) testing is crucial for a near-patient diagnosis to get an immediate preliminary result [1]. In POC, the reliance on large and complex equipment needs to come to an end, as defined by the World Health Organization (WHO) [2, 3]. Therefore, the non-cumbersome microfluidic systems are highly desirable to be integrated into POC devices [4]. The devices generally comprise a microfluidic channel for micro-scale fluid mixing and a micropump to drive the fluid within the miniaturized instrument. It is imperative that the micropump should be designed as a standalone component with very few user interventions during POC testing [5].

In active micropumping, the external power source is manipulated to form a continuous and controllable fluid flow [6]. Studies have been progressing in recent years regarding the design of portable power sources for micropumps that is compatible with POC testing. The sources of power may be derived from acoustic [7] and centrifugal [8] forces, electrical [9] or magnetic [10] fields. However, these auxiliary components inevitably made the POC device become more complex and bulkier [11]. Meanwhile, in passive micropumping, fluid movement can be driven by the momentum of ejected small droplets [12], the concentration difference induced by liquid evaporation [13], the gravitational force [14, 15], or by the capillary effect [16–18]. Nevertheless, these methods are only capable of generating a rather low flow rate. Alternatively, a different approach that uses a sequential finger-actuation method was demonstrated by Yang et al. [19] and Qiu et al. [20]. It is able to produce a sufficiently large volumetric flow rate which is proportional to the exerted pressure during the actuation phase. The aforementioned passive micropumps have been designed to be attached to the inlet of any microchannel. Hence, this would require a micropump pressure that is considerably higher than that of the atmospheric pressure. This method of micropump assembly is susceptible to leakage in any of the ports or tubing networks, especially within a low-structural-integrity microfluidic unit. Another problem arises when these micropumps are required to drive fluids into two or more inlets of a microchannel, by which multiple units of micropumps are required to be separately attached to each inlet.

To address these problems, a number of micropumps that utilize negative pressure (lower than the atmospheric pressure) have been designed and studied [21–23]. For instance, Juncker et al. [22] reported the use of a capillary-drag-type micropump attached to the outlet to collectively drive various fluids from a multi-inlet microchannel. A slightly different configuration was adopted by Liang et al. [23] who utilized the vacuum generated within the microchannel resulting from degassed poly(dimethylsiloxane) (PDMS). It is noted that these designs are only capable of generating a low volumetric flow rate. In

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