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Abstract

Development of Fluid Handling Capabilities for Autonomous Sampling Capsule †

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Abstract: This work focusses on the design of a swallowable smart capsule to collect rumen samples from a cow's rumen and small intestine. The capsule (60 mm long × 25 mm diameter) passively travels along the cow's GI tract, identifies the region of interest, collects a sample, and chemically stabilizes it for offline omics analysis. Key components in the fluidic system include (i) a micro pump, (ii) valves, and (iii) a fluidic reservoir. As a preliminary design step, we investigated sample collection and reagent mixing protocols on a bench-top fluidic system. A model rumen sample (80% glycerol/water) of similar viscosity to rumen fluid was used in our research to evaluate pumping and mixing with a stabilizing reagent.

Keywords: smart capsule; micro pump; microfluidics; GI tract

1. Introduction

Bovine gut microbiota has a vital role in the immune system, digestion, mood, etc., of an animal [1]. Such microbes are also studied to reduce herd greenhouse gas emissions. The proposed smart capsule can sample bovine gut fluid and preserve its integrity by mixing with a microbiota stabilizing reagent. Post capsule recovery, the liquid sample is extracted and genetically analysed to profile bovine health. We envisage that these smart capsules will enable herd-wide sample collection, providing a deeper understanding of how changes in diet, environment, etc., impact the digestive tract microbiota. Initially, we focus on a benchtop fluidic system design to evaluate fluidic components (pumps, valves, fluidics, impeller mixer, etc.) suitable for this application. This will contribute to system miniaturization for capsule integration and further research. The key challenges for the capsule system are the ability to enable robust and reproducible sample collection and reagent mixing.

2. Materials and Methods

Five commercial micropumps were tested for their ability to pump model rumen samples of varying viscosity and solid content. Food dyes were used to visualize liquid flow and quantify fluidic system mixing efficiency. The system sampling and mixing setup is illustrated in Figure 1b. The micropump-aspirated model for rumen fluid had valve 1 open and valve 2 closed, where the reservoir was pre-loaded with 2 mL of preserving reagent. Once the sample (500 µL) was collected in the reservoir, valve 1 was closed and valve 2 opened, configuring a closed-loop system. Reservoir contents were circulated repeatedly within the closed loop until mixing was complete. To assess mixing, as shown in Figure 1a, a tube section was imaged with an epifluorescence microscope. Images were captured during the mixing period. Imaged Red–Green–Blue (RGB) pixel values were extracted from each image using cell-F software. The average green–red pixel intensity

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ratio from each image was plotted against time. The same experiment was repeated for all the pumps evaluated. The second mixing approach incorporated a rotating impeller into a modified reservoir, as shown in Figure 1c.

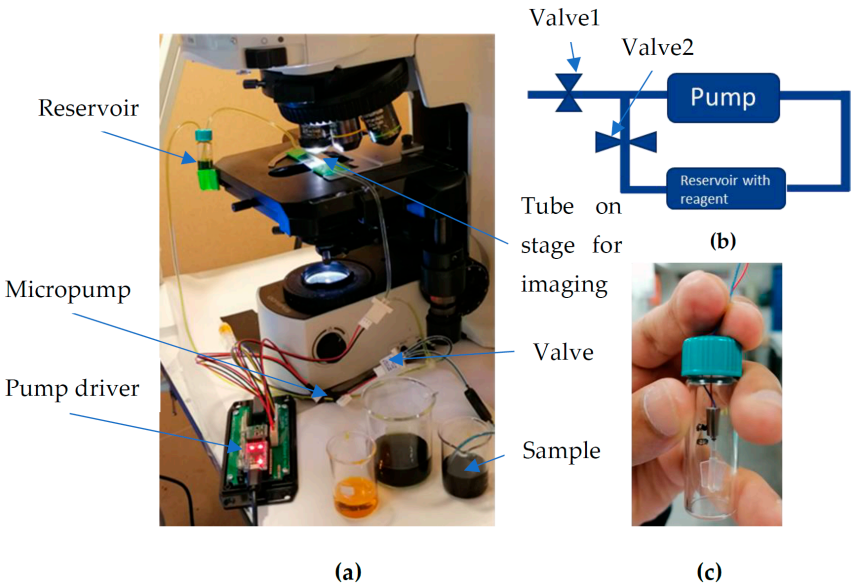

Figure 1. (**a**) Fluidic system under microscope to study mixing; (**b**) schematic of mixing configuration; (**c**) impeller designed for mechanical mixing inside the reservoir.

3. Discussion

The Takasago Peristaltic pump and V100 were deemed suitable for our application, achieving the required flowrate. The P25 had a higher flowrate, but its size was not compatible with the capsule.

Figure 2 highlights the fluidic system mixing time. Full mixing was indicated by plateauing of the curve. At the beginning of the curve, the green–red pixel ratio peaks within a short time as it draws more of the sample dye type (blue) compared to reagent dye (yellow), and as time progresses, the pixel green–red ratio plateaus, indicating full mixing (green). Two repeated tests were undertaken with each micropump. Mixing on the Bartels and Takasago pump took 108 s, whereas mixing on the V100 Xavitech pump took 110 s. When the modified reservoir with the rotating impeller was used, the V100 Xavitech pump took 35 s, which was 3.1 times faster than without the impeller.

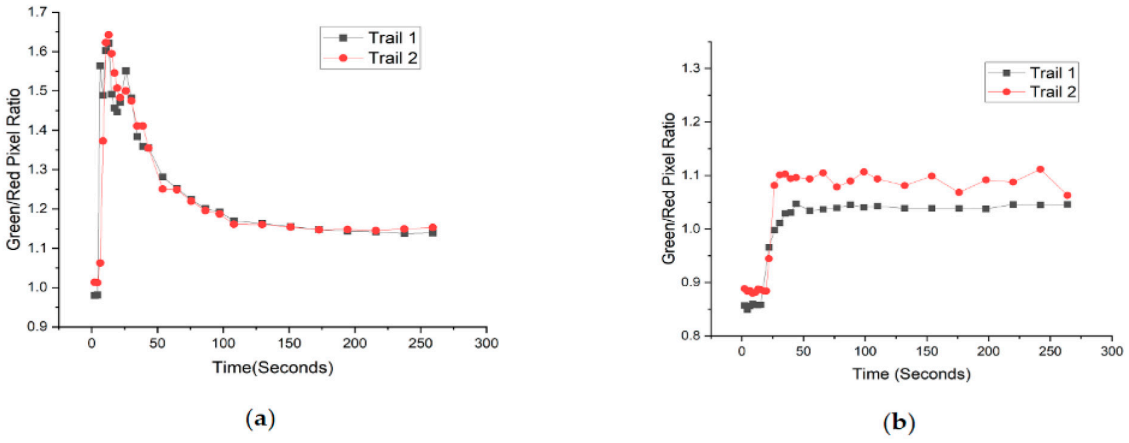

Figure 2. Graphs showing time taken to mix: (**a**) time taken by mp6liq micropump to mix; (**b**) time taken to mix when a mixing impeller is used.

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Conflicts of Interest: The authors declare no conflicts of interest.

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