TOWARDS FLOW VISUALIZATION EXPERIMENTS IN A MASSIVELY ARRAYED MICROFLUIDIC PRODUCTION SYSTEM

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Background and Motivation

- Over the past 20 years, there has been growing interest in the formation of droplets using microfluidic approaches for
  - size and the
  - polydispersity index (of the droplet).

These techniques have several applications summarized in fig 1 –

- Advantages of microfluidic channels include –
  - considerably more control of the size and
  - can be used to produce more uniform particles.
- NPs used as drug nanomedicine offer –
  - Enhanced permeability
  - Higher retention in vivo.

- Using a massively arrayed fiber reactor (FR), nanoparticles (NP) of PNIPAm used as drug delivery agents have been produced (see Fig 2). (Jaminkhindar et al (2006)).

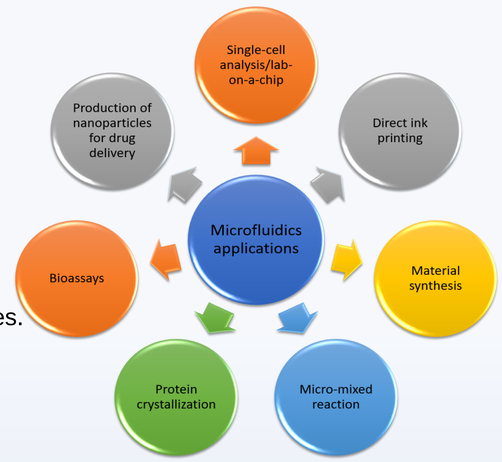


Figure 1: (above) Applications of microfluidics

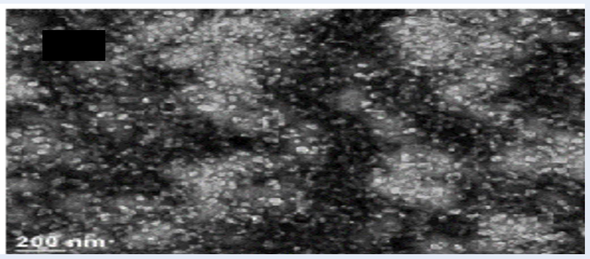


Figure 2: (left)
TEM images of PNIPAm nanoparticles produced in the reactor. The average droplet size of 37.5nm and a PDI range of 0.26 – 0.3.

Size and surface characteristics of NPs can be tuned using various process parameters, such as –

- Relative flowrates of multiphases.
- Concentration of surfactant

Studies show that droplet size have a correlation with relative flow rate as modeled by the scaling law -

$$\frac{L}{w} = 1 + \alpha \frac{Q_d}{Q_c};$$

$w = channel\ width,$
$L = channel\ lenght,$
$\alpha = characteristic\ constant\ for\ geometry\ of\ device,$
$Qd, Qc = flow\ rate\ of\ dispersed, continuous\ phase\ respectively$

Furthermore, more studies on droplet breakout in the microchannel is reveal that 3 regimes are possible at the T-junction depending on the capillary number Ca_c of the continuous fluid.

These regimes are:
i) Squeezing regime (Ca_c < 002)
ii) Squeezing regime (Ca_c < 0.002)
iii) Transient regime (0.002 < Ca_c < 0.01

$$Ca_c = \frac{U_c \mu_c}{\gamma};$$

$Uc, \mu c = flow\ rate, viscosity\ of\ continuous\ phase\ respectivly,$
γ = interfacial tension

These regimes occur due to the interplay between three forces –
1. Shear force of continuous phase on emerging droplet
2. Laplace force inside droplet dur to interfacial tension. (Thorsen et al (2001)).
3. Increase of upstream pressure in continuous phase due to droplet obstructing channel width.

About the reactor

The FR consists:
massively arrayed reactor
T-junction type.
- Steel fibers (diameter of 22microns)

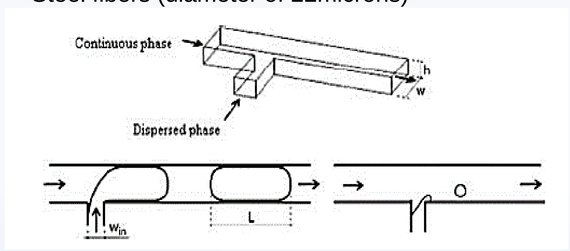
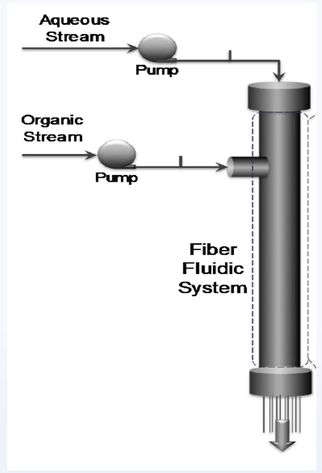


Figure 3: Mechanisms of Droplet formation and the fiber reactor



Flow Visualization

In the study, we would like to visualize the flow in the reactor by
- altering the fluid flow well enough so as to detect directly how the fluid flows with negligible alteration to the fluid motion.

- The approach would employ the following-
  - Scalar based flow visualization methods
  - Using fluorescent or phosphorescent particles.
  - and microscope and laser sheet.

The objective of the research is –
- Model and measure the effects of injection type and
- channel diameter on the two phase flow;
  - droplet formation,
  - breakout, and
  - coalescence

in the fiber reactor.

Present work

Design and build a prototype with viewing windows cut on the sides of the reactor.

Use light emitting particles (fluorescence) and a laser sheet, Microscope to capture visualize flow. (see figure below).,

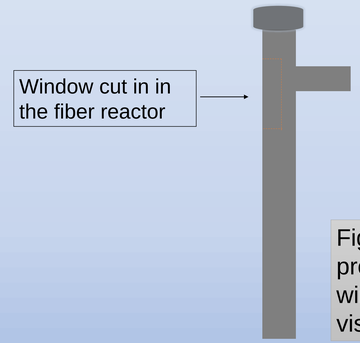


Figure 4: Design of FR prototype with a viewing window for flow visualization

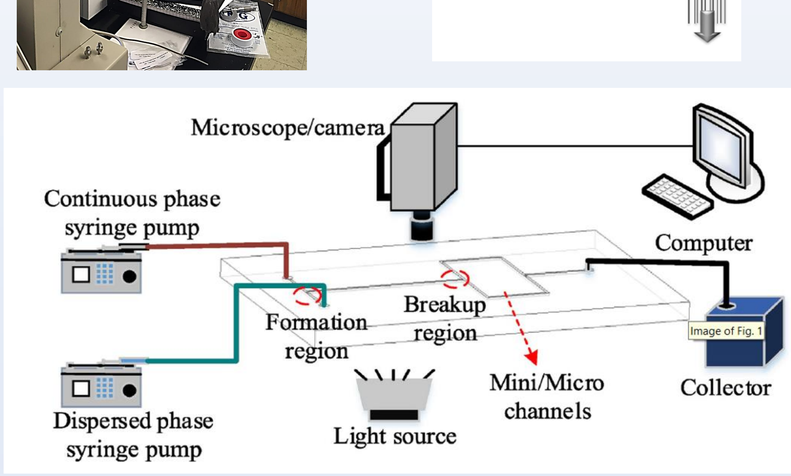


Figure 5: (a) (Upper left) Lab setup (b) (upper right) Schematic of FR, © (bottom) typical flow visualization experimental set-up in microfluidic systems.

References

1. Jingzhi Zhang, Li Lei, et al. , An improved method to visualize two regions of interest synchronously in microfluidics, Flow Measue and Instrum, 2020.
2. Sinton D.. Microscale flow visualization, Microfluid Nanofluid (2004).
3. Xu J.H. et al Correlations of droplet formation in T-junction microfluidic devices: from squeezing to dripping (Microfluidic Nanofluidic (2008).
4. Garstecki Piotr et al., formation of droplets and bubble in a Microfluidic T-junction – scaling and mechanism of breakup, lab on a chip (2006).
5. Jamkhindinkar S., Stretz H. et al High throughput fiber reactor process for organic nanoparticle production: Poly(N-isopropylacrylamide, Poly(acrylamide), and Alginate, (Journal of Appl Polymer Sci. (2017).