External Field Induced Flow Patterns in Micro-scale Multiphase Flows

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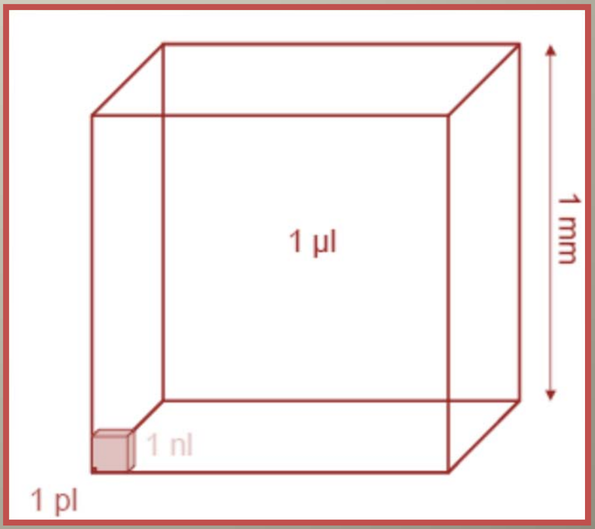
➢ PRESENTATION PLAN

- ❖ INTRODUCTION
- ❖ APPLICATIONS/MOTIVATION
- ❖ USE OF COMSOL MULTIPHYSICS
- ❖ RESULTS

INTRODUCTION

➢ INTRODUCTION

- ❖"Fluidics" means handling of liquids and/or gases
- ❖"Micro" means at least one of the following features:
  i. Small volumes (µl; nl; pl)
  ii. Small size
  iii. Low energy consumption
  iv. Use of special effects:
     - Surface tension
     - Laminar flow
     - Capillary forces



➢ Materials of fabrication of microfluidic devices

❖ **Silicon / Si compounds:**
- Classical MEMS approach
- Etching involved

❖ **Polymers/Plastics:** →

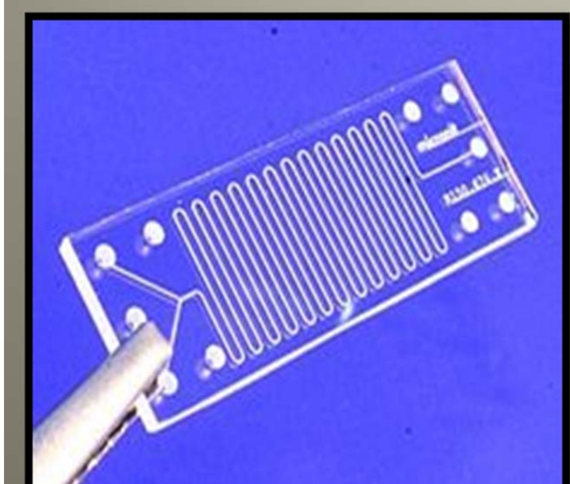
➢ Newer methods:
- Imprinting and hot embossing
- Injection Molding
- Laser photo ablation
- Soft Lithography
- Photolithography
- X-Ray Lithography(LIGA)

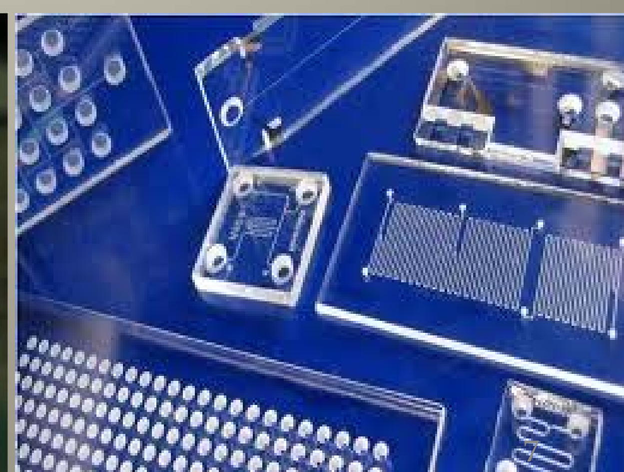
Polymers:
PDMS
PMMA
POLYURETHANE
POLYIMIDE
POLYSTYRENE

APPLICATIONS/MOTIVATION

➢ APPLICATIONS

- Controlled drug delivery systems and pneumatics
- Cooling of microelectronic devices and flow control
- MEMS / NEMS devices and sensors
- Power systems (Fuel cells, micro-combustors)
- Micro-reactors, micro-mixers and heat exchangers
- Miniature systems in chemical and biological analysis (Lab on a chip or μ-Total Analysis Systems)





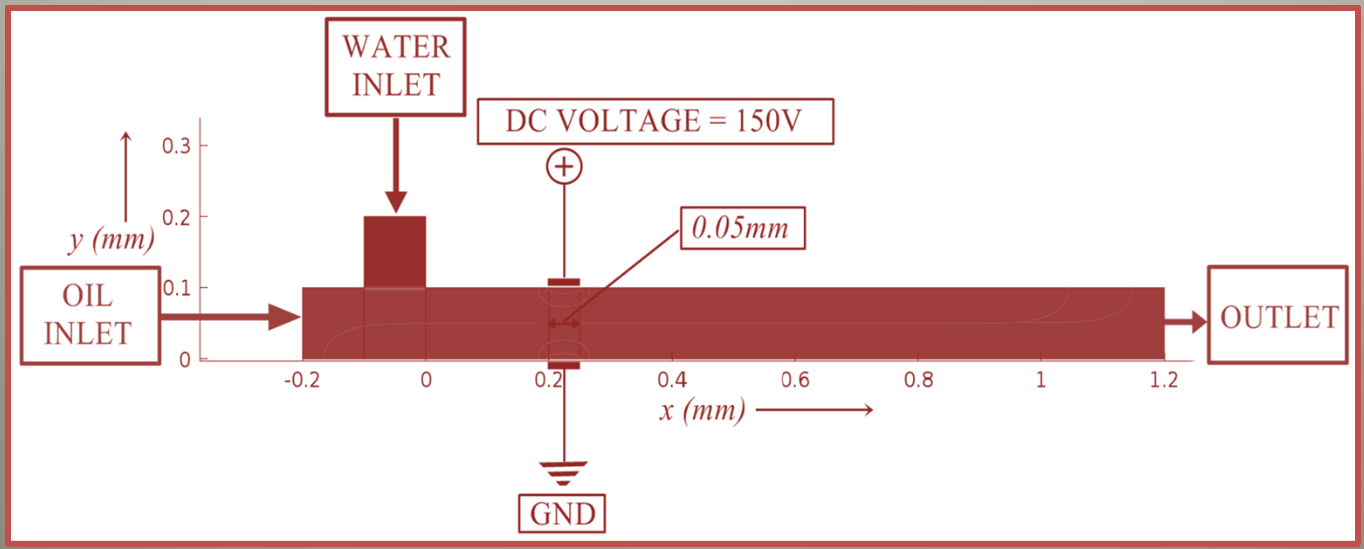
➢ MOTIVATION

- ❖ Study the flow regimes for different velocity ratios of a two-phase laminar flow system in a micron sized channel
- ❖ Study the effect of the parameters like viscosity, contact angle, surface tension on these flow regimes
- ❖ Manipulation of the flow regimes by enforcing external electric field (AC or DC).
- ❖ Achieve droplet driven flow from any type of flow pattern "Drop on Demand"

USE OF COMSOL MULTIPHYSICS

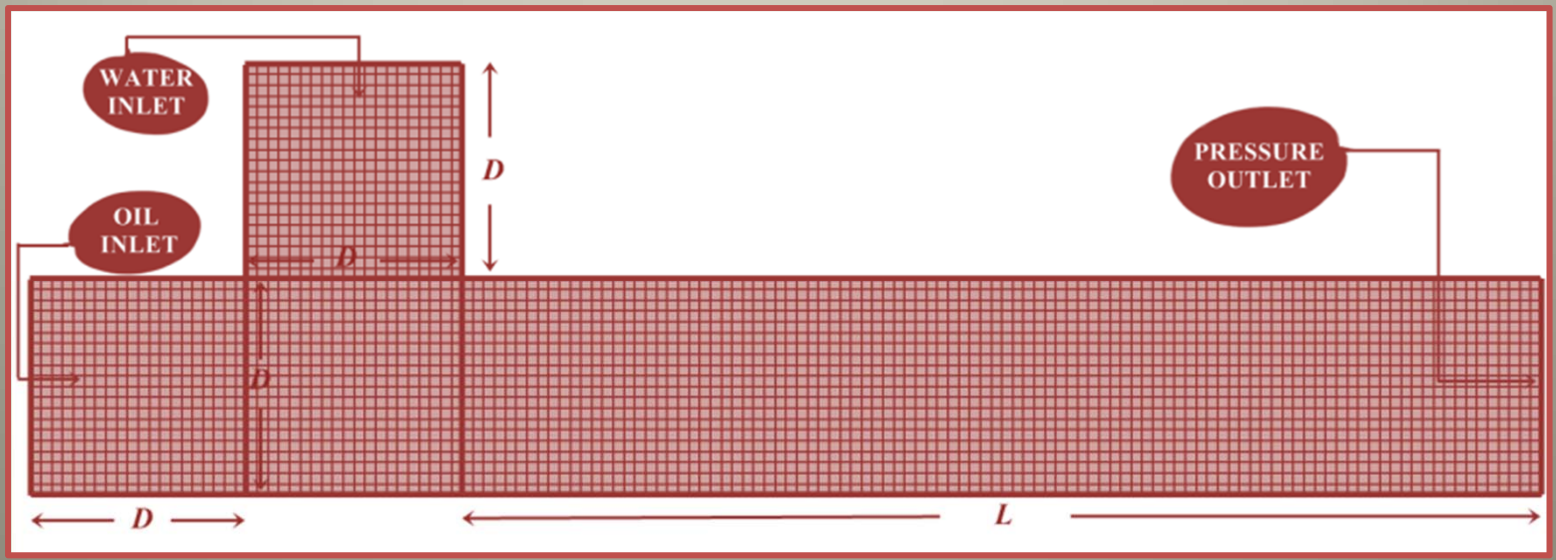
➢ GEOMETRY

- Selection of an appropriate coordinate
- Determining the domain size and shape
- Simplifications, if possible
- Shapes needed to be used to best resolve the geometry (lines, circular, ovals, etc.)



➢ MESH

- Meshes should be well designed to resolve flow features which are dependent upon flow condition parameters such as the grid refinement inside the wall boundary layer



PHYSICS

- **Flow conditions:**
  – Inviscid, viscous, laminar, turbulent, etc

- **Fluid properties:**
  – Density, viscosity, electrical and thermal properties, etc.

- **Selection of models:**
  – Different models usually fixed by codes, options for user to choose

- **Initial and Boundary Conditions:**
  – Not fixed by codes, generally user needs to specify them for different applications

➢ SOLVING

- Setup appropriate numerical parameters
- Choose a suitable solver
- Solution procedure (e.g. incompressible flows)
- Get flow field quantities, such as velocity, turbulence intensity, pressure and integral quantities (lift, drag forces)

➢ GOVERNING EQUATIONS

- **Conservation of Mass – the continuity equation:**

$$\frac{\partial \rho}{\partial t} + \nabla.\left(\rho \mathbf{u}\right) = 0$$

$$\nabla \cdot \mathbf{u} = 0$$

$$\rho = \rho_c + \left(\rho_d - \rho_c\right) V_{fd}$$

$$\eta = \eta_c + \left(\eta_d - \eta_c\right) V_{fd}$$

- **Navier-Stokes Equation:**

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u}.\nabla\mathbf{u}\right) = \nabla.\overleftrightarrow{\boldsymbol{\sigma}} + \mathbf{f} = -\nabla p + \eta\nabla^2\mathbf{u} + \mathbf{f}_e + \mathbf{f}_{st}$$

- **Electric force:**

$$\mathbf{f}_e = \nabla \cdot \mathbf{T}^m$$

Where, $\mathbf{T}^m$ = Maxwell's stress tensors

➢ GOVERNING EQUATIONS

- **Electrostatics equation:**
  - **Gauss's Law**

$$\nabla \cdot \left(\varepsilon_0 \varepsilon_r \mathbf{E} \right) = 0$$

$$\mathbf{E} = -\nabla V$$

  - **Electrical displacement**

$$D = \varepsilon_0 \varepsilon_r \mathbf{E}$$

ε_0 = permittivity of free space

ε_r = relative permittivity of the fluids

V_{fc} = Volume fraction of continuous phase

V_{fd} = Volume fraction of dispersed phase

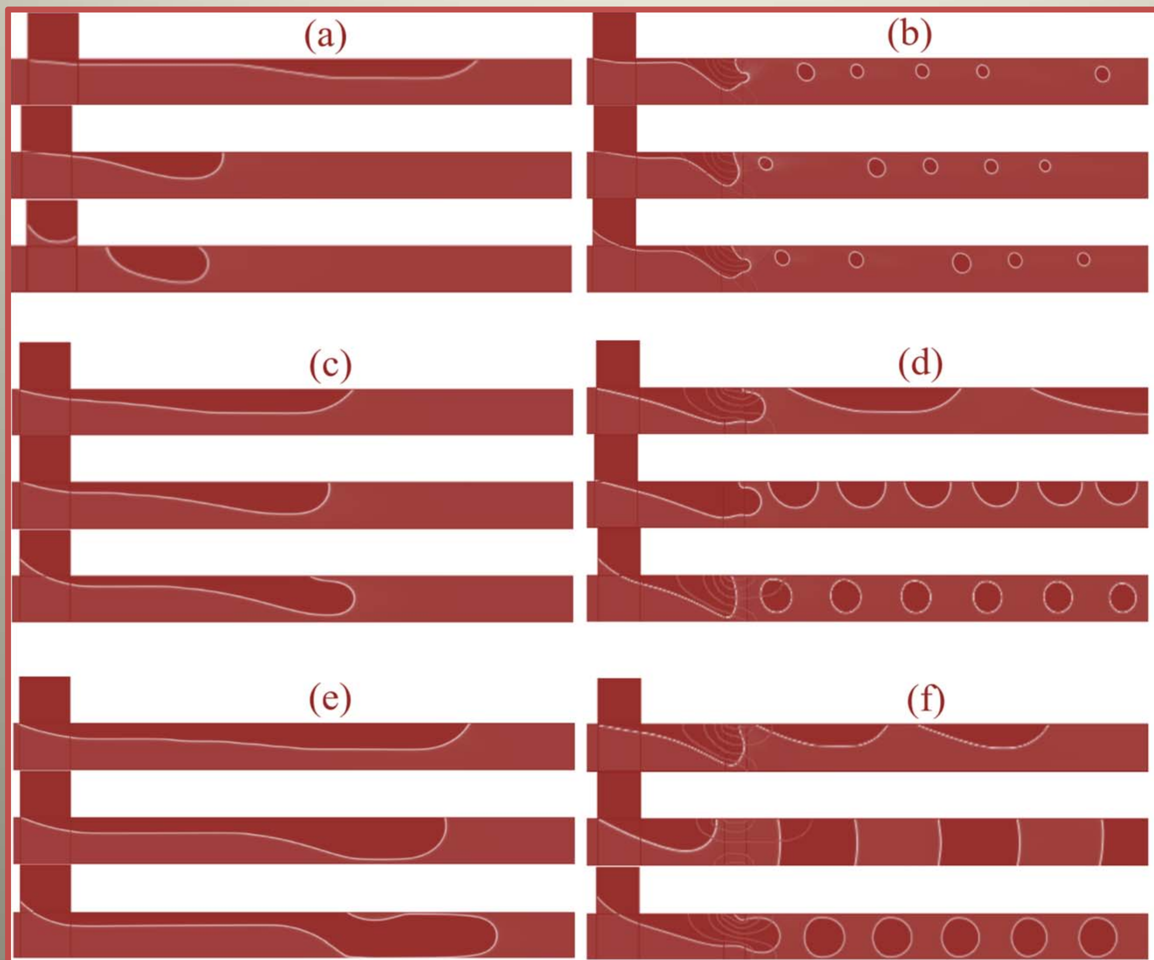
$$\left(\varepsilon_r = \varepsilon_{rc} V_{fc} + \varepsilon_{rd} V_{fd} \right)$$

RESULTS

➢ RESULTS: DC Voltage Results (150V)

Contact angle = θ, Velocity ratio = Q

$\left(Q = v_D / v_C\right)$



(a), (b): $\theta = 45^\circ$, $\theta = 90^\circ$, $\theta = 135^\circ$ — $Q = 0.1$

(c), (d): $\theta = 45^\circ$, $\theta = 90^\circ$, $\theta = 135^\circ$ — $Q = 0.5$

(e), (f): $\theta = 45^\circ$, $\theta = 90^\circ$, $\theta = 135^\circ$ — $Q = 1$

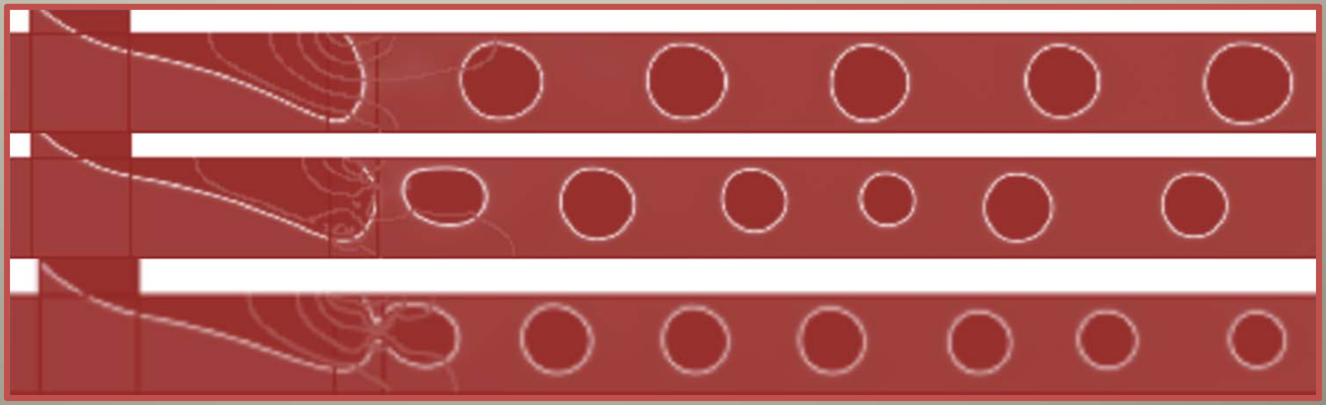
➢ RESULTS: AC Voltage Results (220V)

- With increasing frequency of the voltage applied, the droplet frequency increases
- This helps to achieve more control on the microfluidic system

$f = 50Hz$

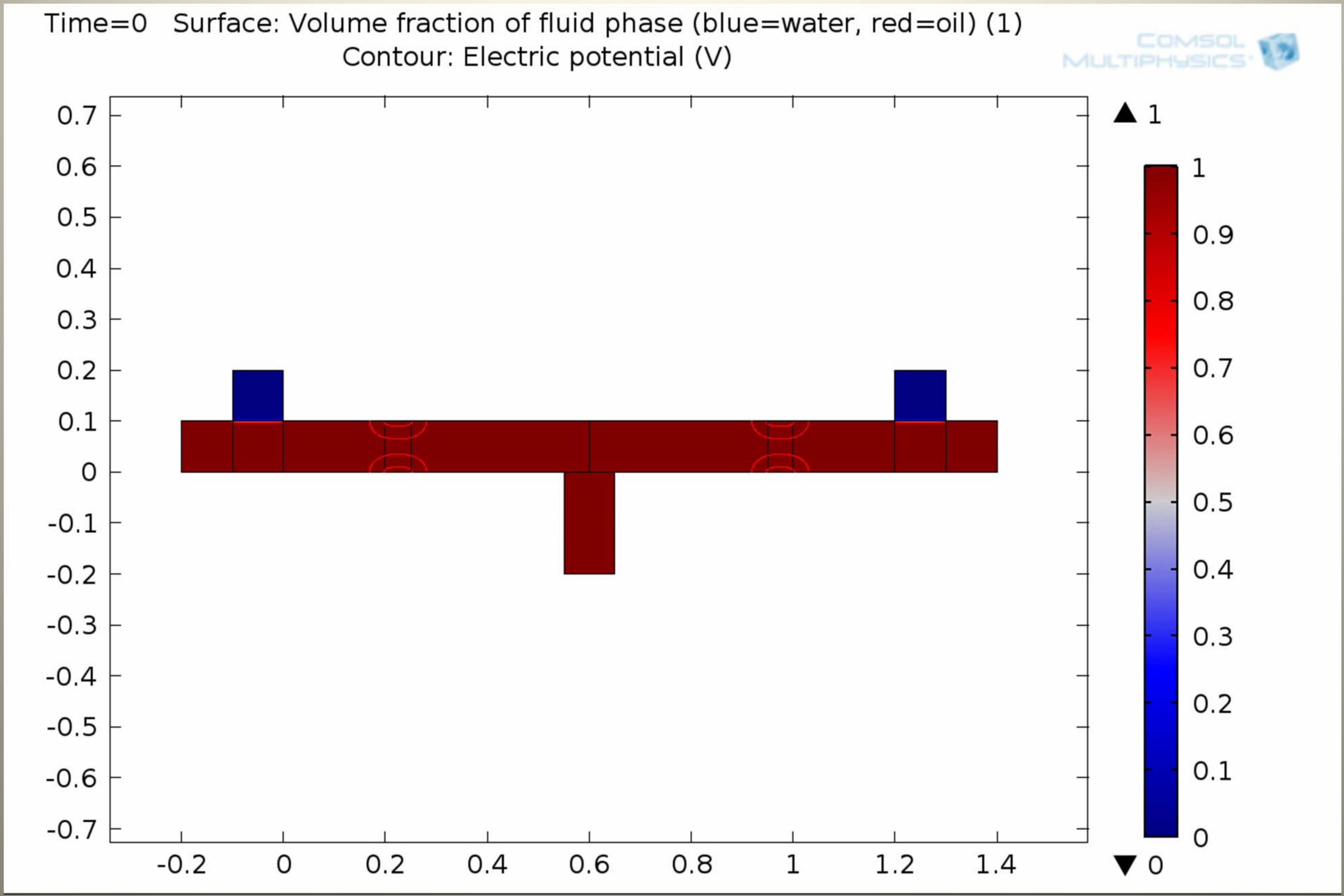
$f = 500Hz$

$f = 5000Hz$



$Q = 0.5$

$\theta = 135^\circ$



Time=0 Surface: Volume fraction of fluid phase (blue=water, red=oil) (1)
Contour: Electric potential (V)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
▲ 1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
▼ 0

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THANK YOU!!