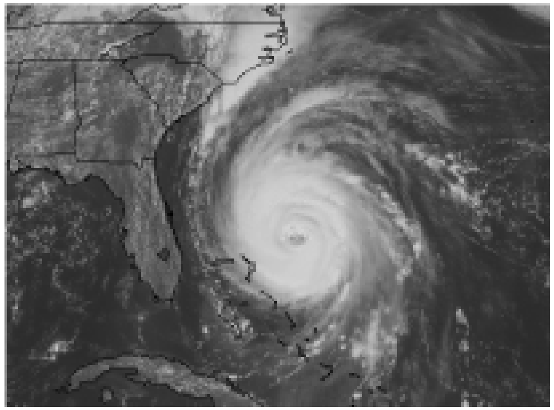
What is Fluid Mechanics ?

- A branch of applied physics that is concerned with the motion of fluids (liquid or gas) and the forces associated with that motion
- A branch of mechanics or physics that seeks to describe or explain the nature of physical phenomena that involve the flow of liquids or gases

Scope of Fluid Mechanics

- natural phenomena
- hydraulics
- aircrafts



NASA Dryden Flight Research Center Photo Collection

X-33 artist concept - 1999

Why Process Fluid Mechanics ?

emphasis is on the problems associated with the process industries

examples:

IT:	- semiconductor device fabrication
	- chemical vapor deposition (CVD)
	- hard disk drive
	(microfluidics)
	(biomedical flow device)
	(DNA chip)
BT:	- blood flow
	- microcirculation
	- stenosis
Food:	- ice cream
	- chocolate
	(drop deformation)
Industrial:	- agitated tank
	- extruder
Fundamentals:	
	- pipe flow, particulate flow
	- contraction flow
	- flow around an obstacle

Why Process Fluid Mechanics ?

Why Chemical Engineering ?

- Chemical Engineering is what chemical engineers do.
- material/process
- chemistry/physics/mathematics

Why Transport Phenomena

- fluid mechanics (momentum transfer)
- heat transfer
- mass transfer

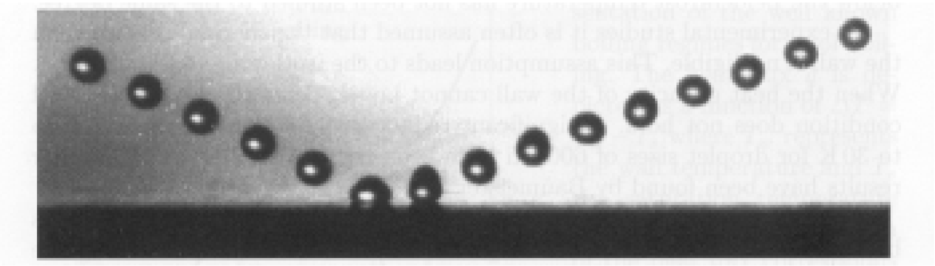
Why Process Fluid Mechanics

- fundamentals
- industrial
- design
- modelling
- engineering sense
- insight for solving the physical problems

What is Fluid ?

solid / liquid / gas
elastic / viscous
Hookean solid / Newtonian fluid
non-Newtonian fluid

viscoelastic



Song of Deborah , Judges V.5
"The mountains flowed at the presence of the Lord,"

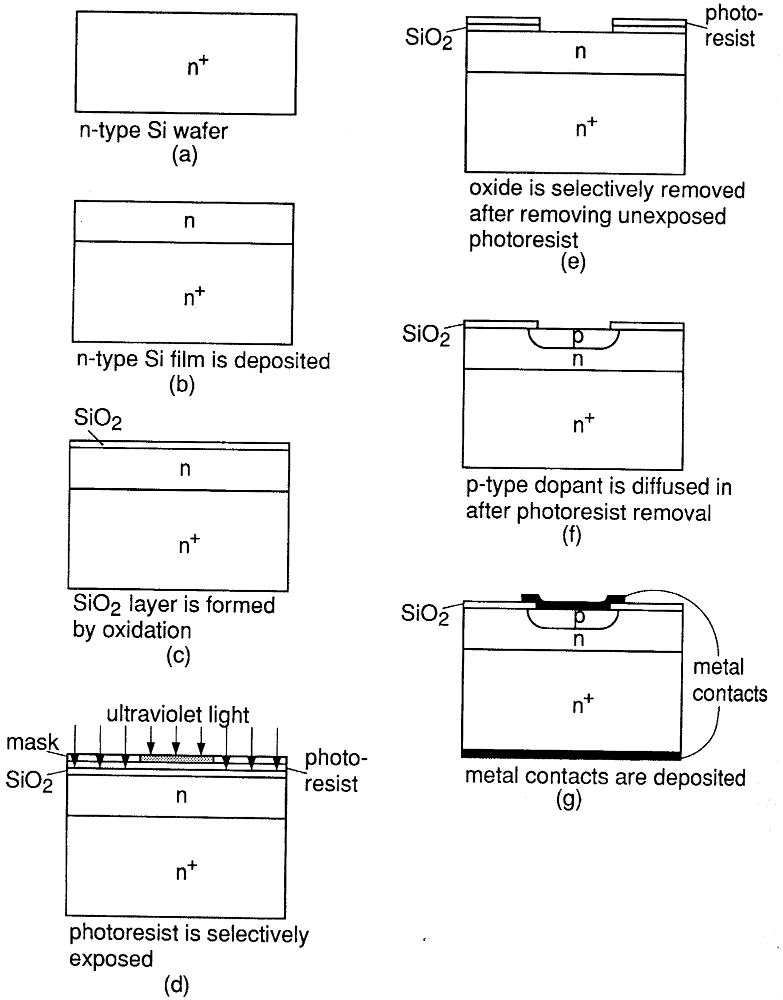
processing of water drop during the inverval of 10^{-15}sec

$$\text{Deborah number} = \frac{\text{characteristic time of the material}}{\text{characteristic time of the process}}$$

characteristic time of the material

water 10^{-12}sec , polymer 10^{-3} to 10^{1}sec , glass 10^{6}sec , mountain 10^{12}sec

Semiconductor Device Fabrication



n-type Si wafer
(a)

n-type Si film is deposited
(b)

SiO_2 layer is formed by oxidation
(c)

photoresist is selectively exposed
(d)

oxide is selectively removed after removing unexposed photoresist
(e)

p-type dopant is diffused in after photoresist removal
(f)

metal contacts are deposited
(g)

Fig. 6.3-4 Semiconductor device fabrication. (Redrawn from E. S. Yang, *Fundamentals of Semiconductor Devices*, Copyright 1987, McGraw-Hill, New York, Reproduced with permission of McGraw-Hill.)

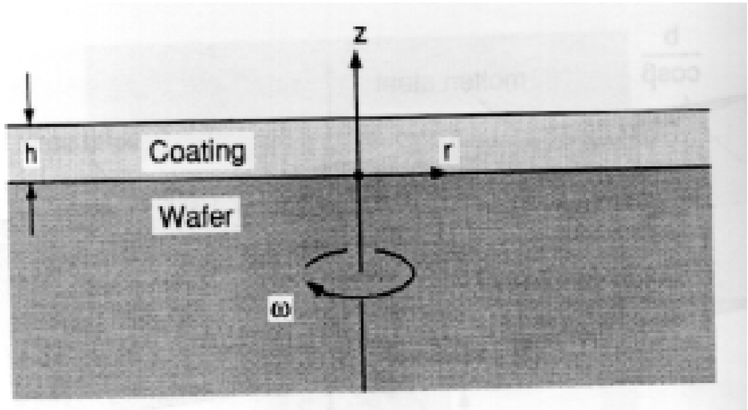


Fig. 7.3-1 Spin coating a photoresist film on a wafer.

$$h=\left(\frac{3\mu}{4\rho\omega^2 t}\right)^{1/2}$$

not a function of initial thickness

Chemical Vapor Deposition (CVD)

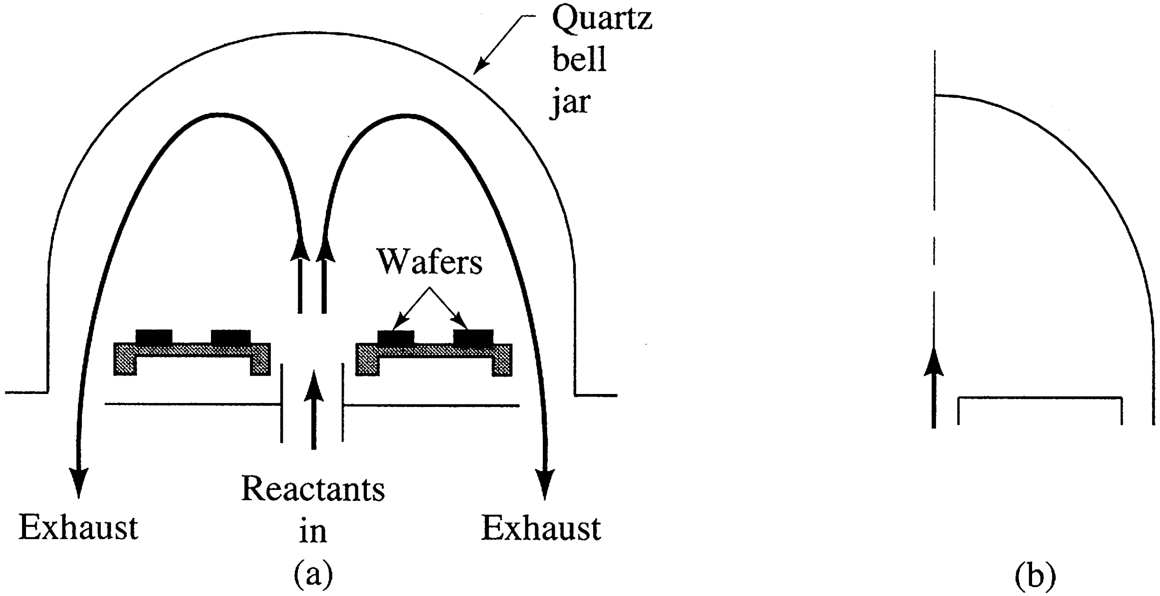


Figure 8.2.2 (a) The bell jar reactor and (b) a geometrical simplification of the boundaries for numerical simulation of the flow field.

Chemical Vapor Deposition (CVD)

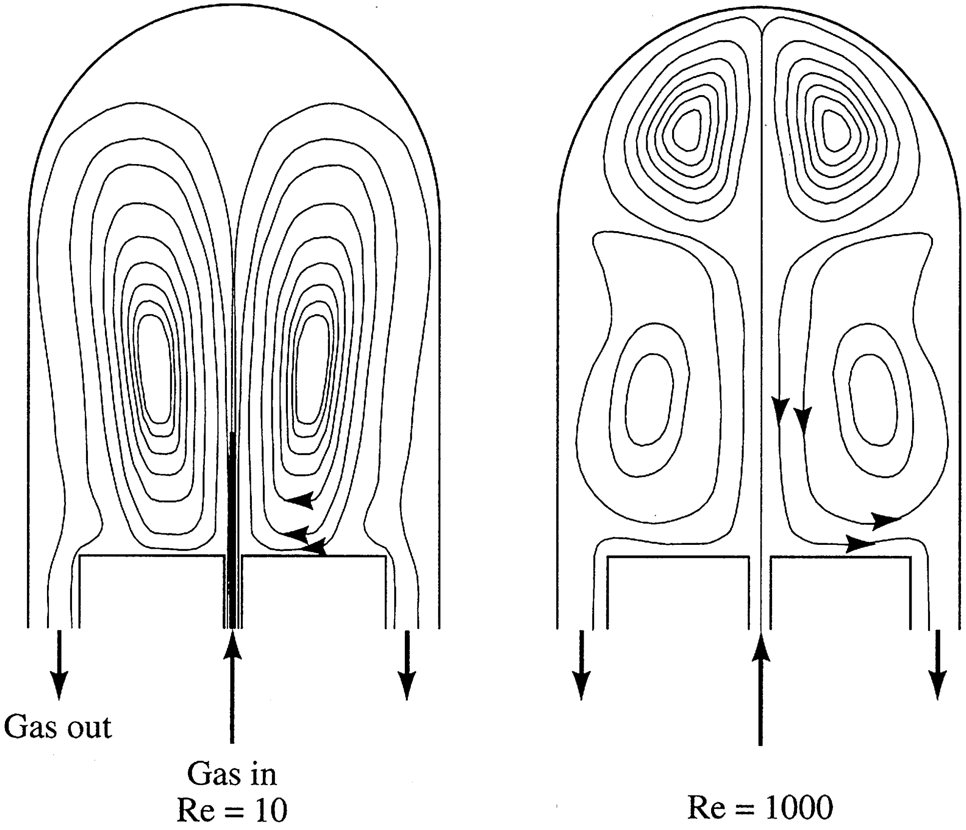
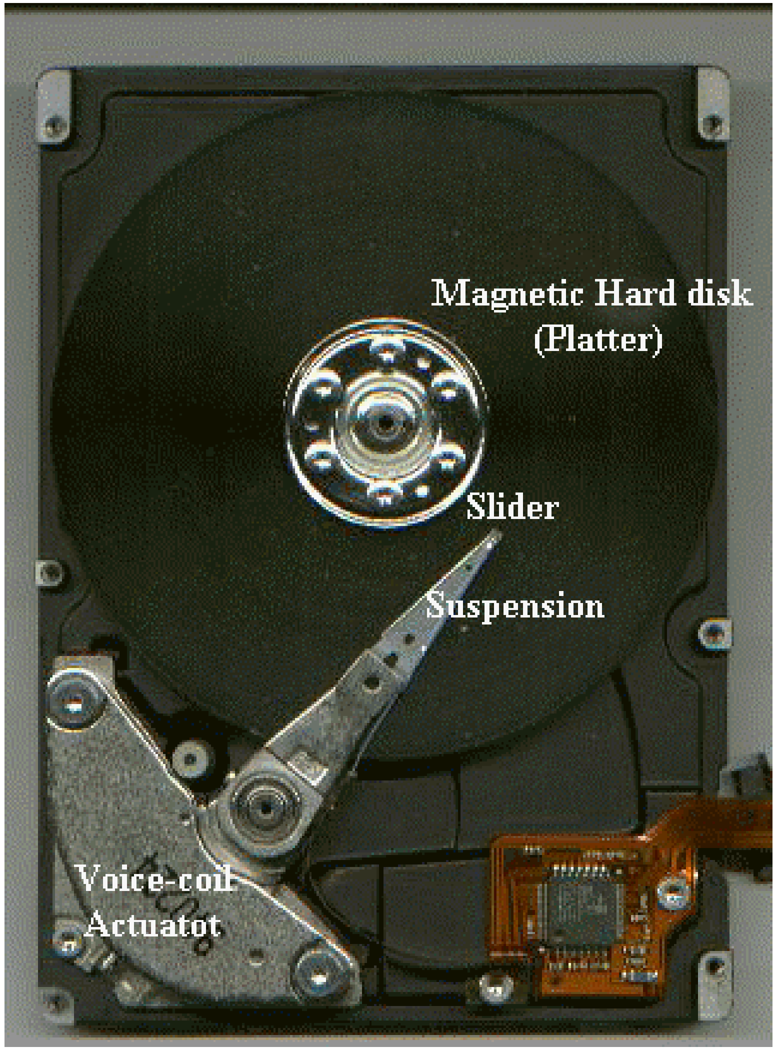
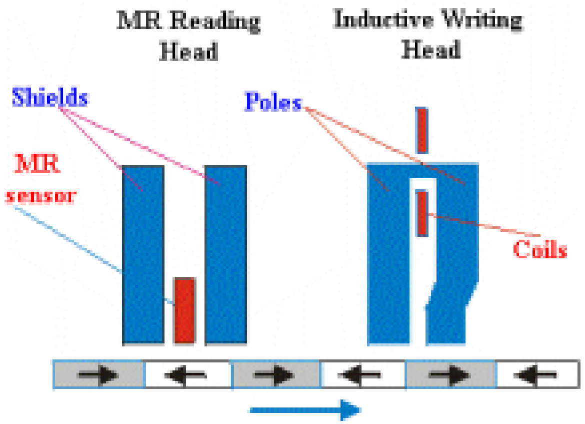
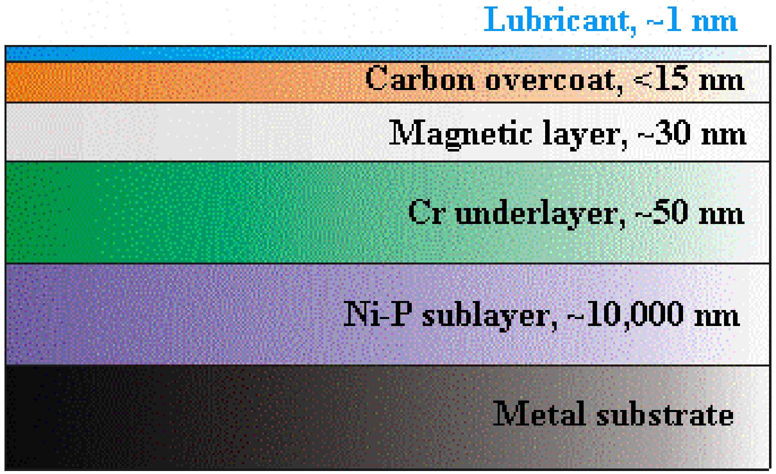


Figure 8.2.3 Streamlines for gas flow through an isothermal bell jar reactor.

Hard Disk Drive







Lubricant, ~1 nm

Carbon overcoat, <15 nm

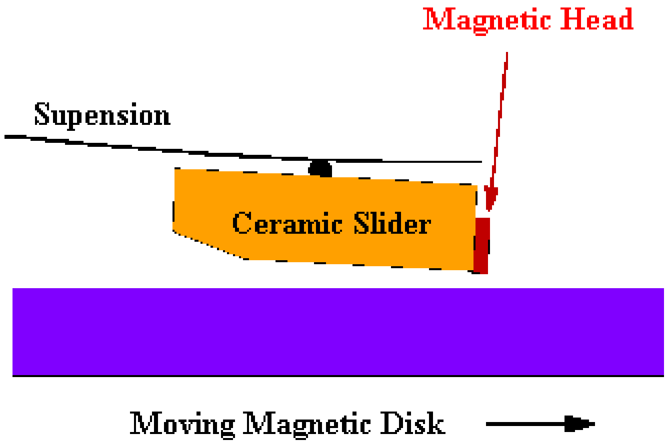
Magnetic layer, ~30 nm

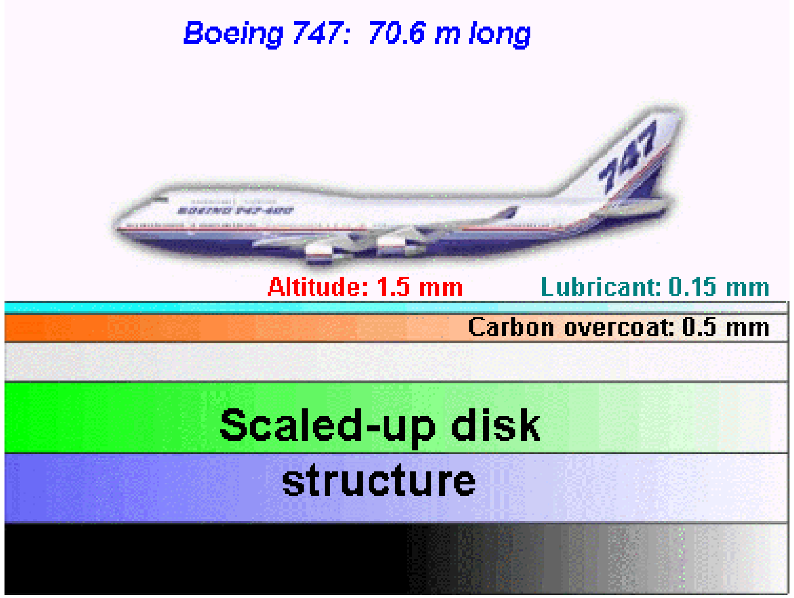
Cr underlayer, ~50 nm

Ni-P sublayer, ~10,000 nm

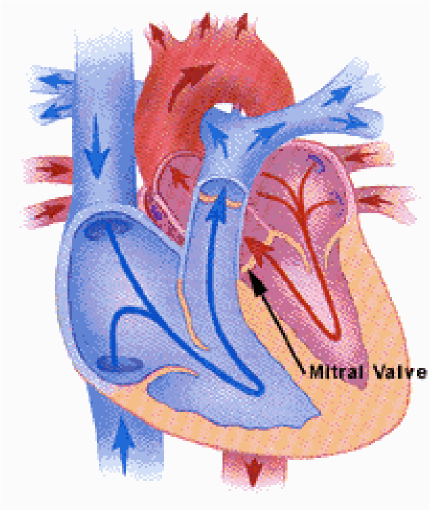
Metal substrate

Hard Disk Drive

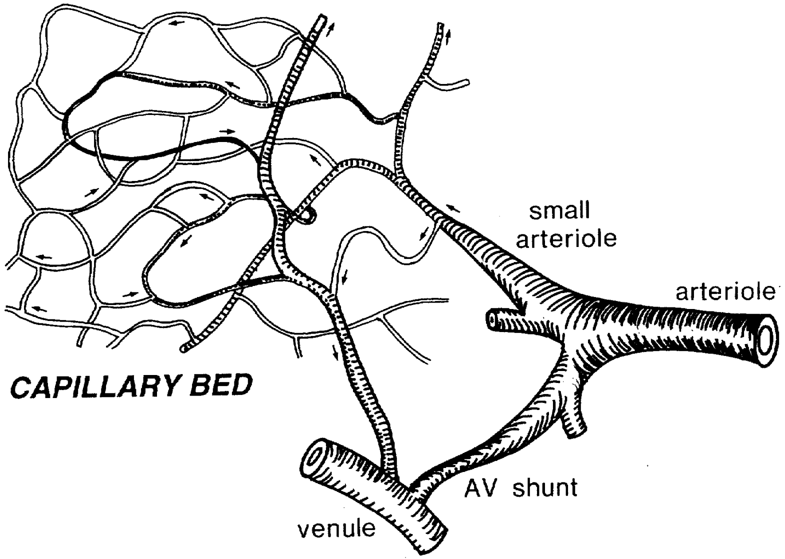




Blood Flow



Normal Heart
red = oxygenated blood
blue= unoxygenated blood



-16. **The microcirculation,** which includes the arterioles and the capillary bed. Note the ıce of arteriolar-venule (AV) shunts, which can open or close to increase the amount of actually in the capillary bed.

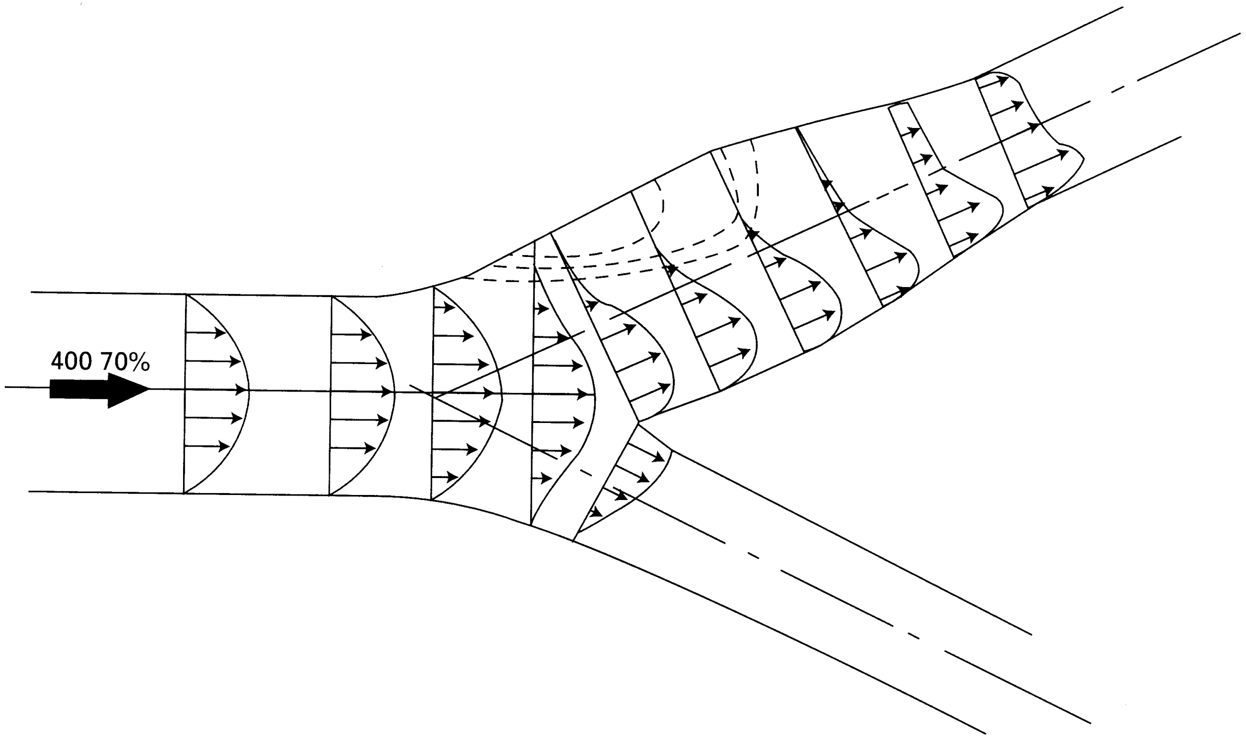


Fig. 2.25 Axial velocity profiles in a model of the carotid bifurcation. Dashed lines in the sinus denote the extent of the region of reversed axial flow for different flow divisions for an upstream Reynolds number of 400. Note skewing of profiles towards the flow divider. Reproduced from Giddens *et al.* (1985)

Blood Flow

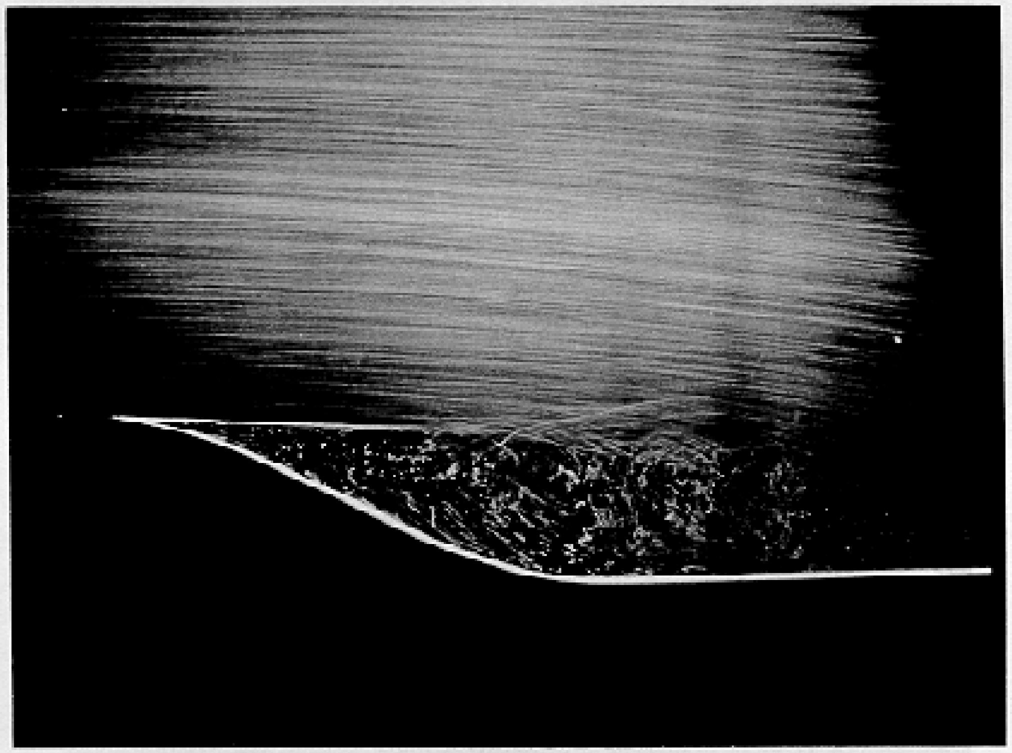


FIGURE 3.17:1. Flow separation from a curved wall. The laminar boundary layer has a Reynolds number of 20,000 based on distance from the leading edge (not shown). Because it is free of bubbles, the boundary layer appears as a thin dark line at the left. It separates tangentially near the start of the convex surface, remaining laminar for the distance to which the dark line persists, and then becomes unstable and turbulent. From Werlé (1974), an ONERA photograph, by permission.

Blood Flow

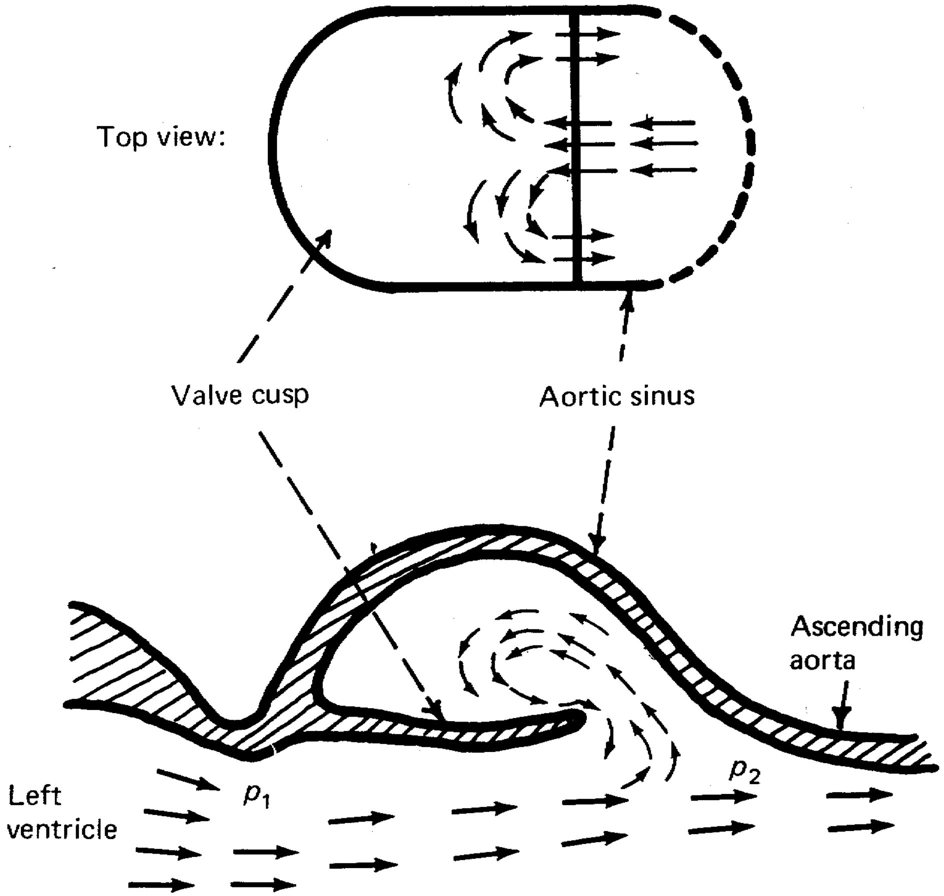


FIGURE 2.5:4. Flow pattern within the sinus of Valsalva.

Blood Flow

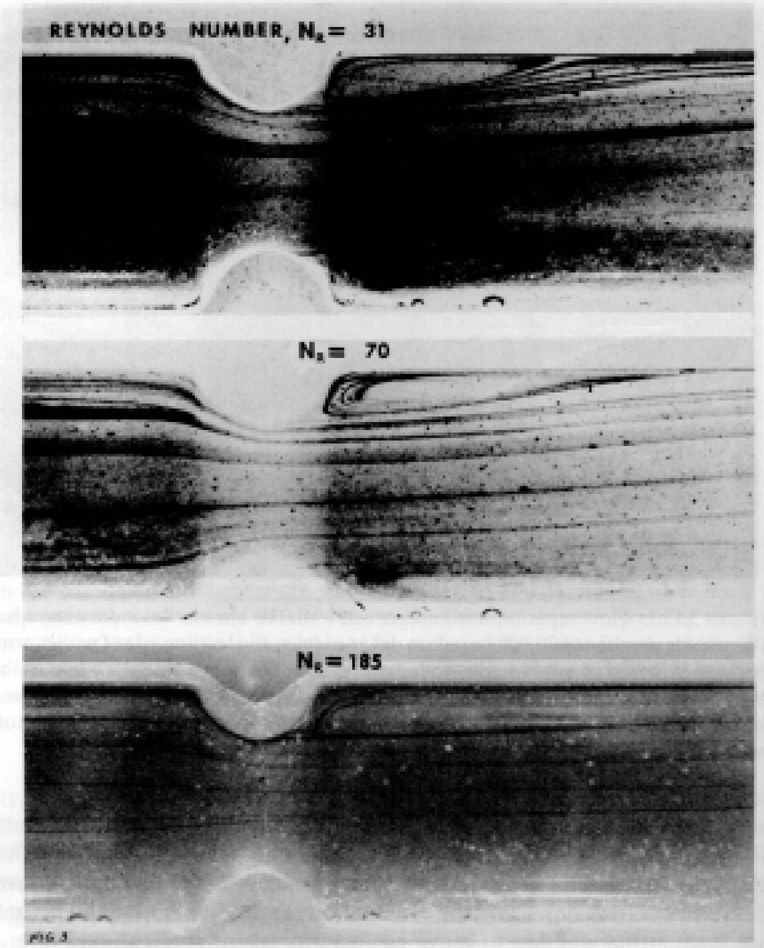


FIGURE 3.17:2. Flow separation in a model of stenosis in a circular cylindrical tube at Reynolds numbers of 31, 70, and 185. From Lee, J.S., and Fung, Y.C. (1971) “Flow in nonuniform small blood vessels.” *Microvasc Res.* 3: 272–287, by permission.

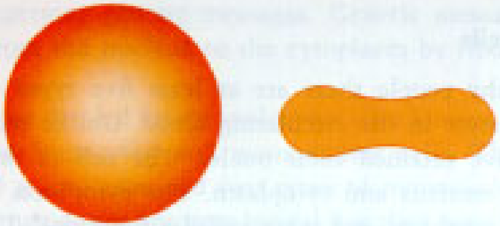
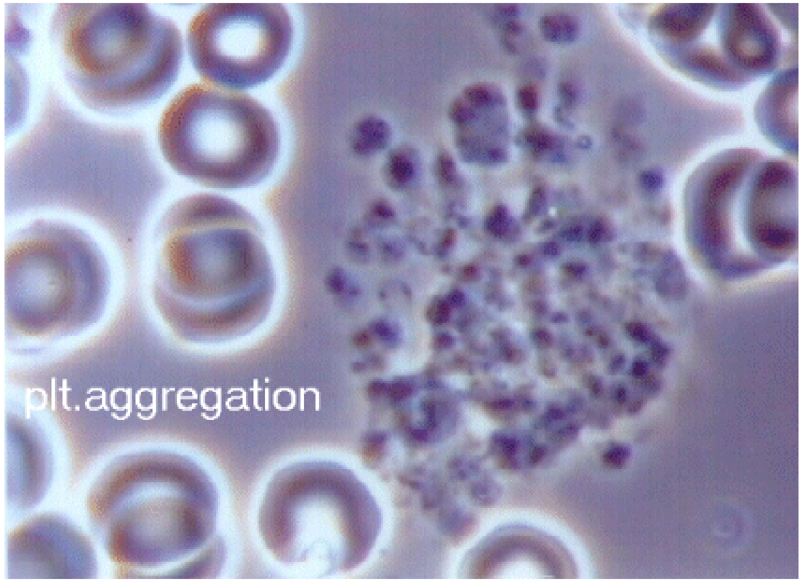
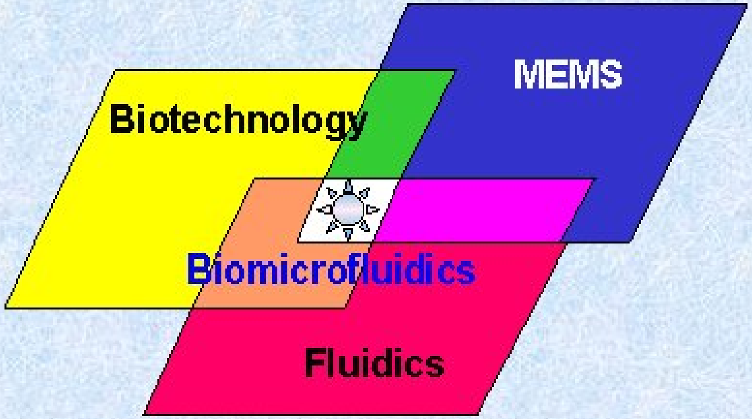


Fig. 1.2 A diagram of a red cell viewed from above and in cross-section.



• What is biomicrofluidics?



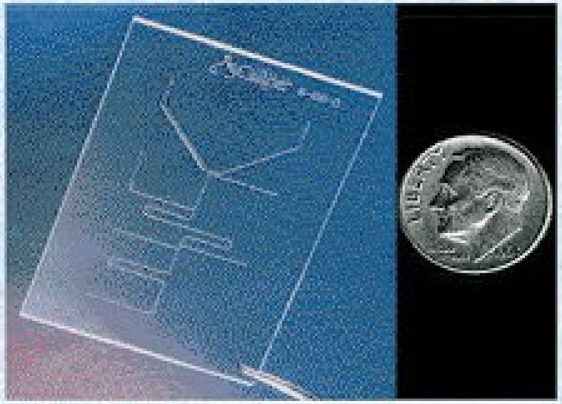
MEMS

Biotechnology

Biomicrofluidics

Fluidics

• Application



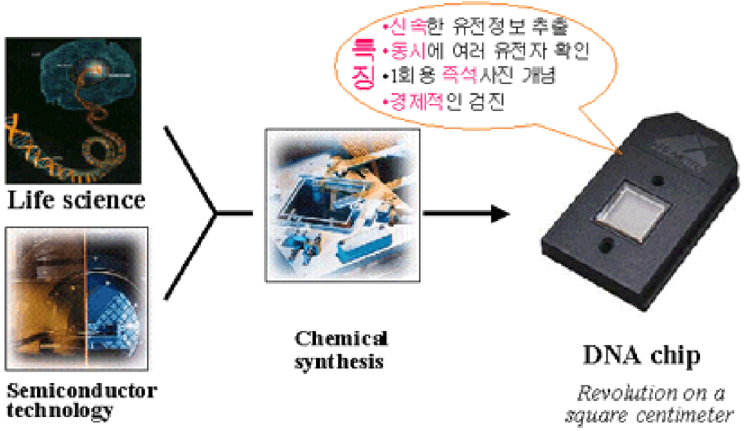
Hereditary disease DNA test

Human blood test

Human disease alarm system

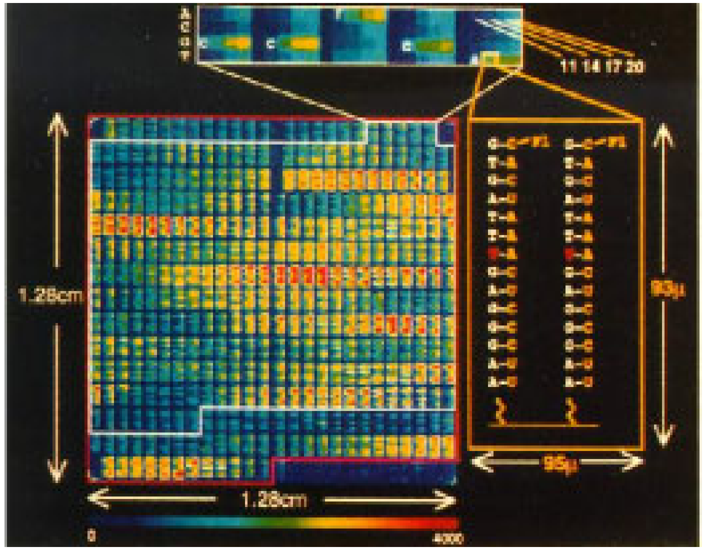
DNA Chip

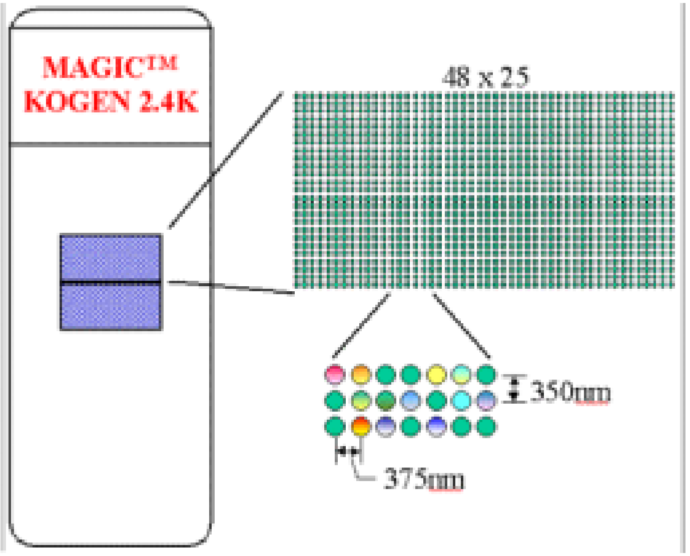
DNA Chip : Revolution on a Square Centimeter



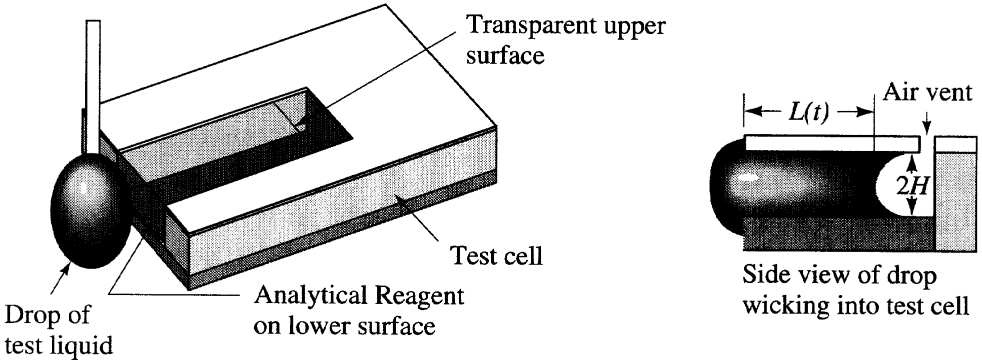
특징
- 신속한 유전정보 추출
- 동시에 여러 유전자 확인
- 1회용 즉석사진 개념
- 경제적인 검진

Revolution on a square centimeter





DNA Chip



Side view of drop wicking into test cell

Figure 4.5.3 Device in which a drop is drawn into a narrow planar channel by capillary action (wicking).

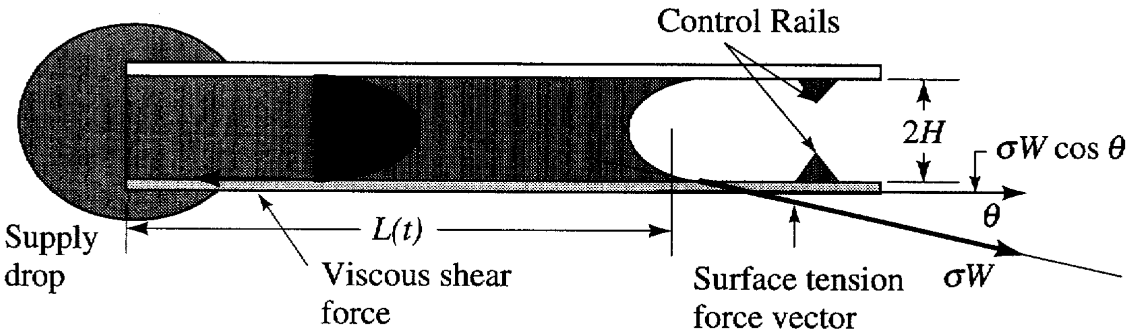
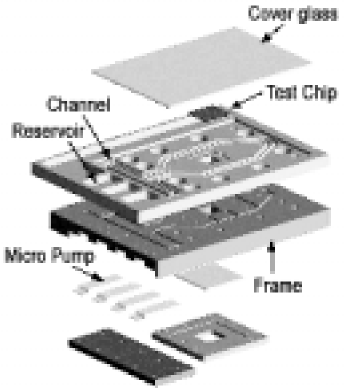


Figure 4.5.4 Force diagram for wicking of a drop into the channel.

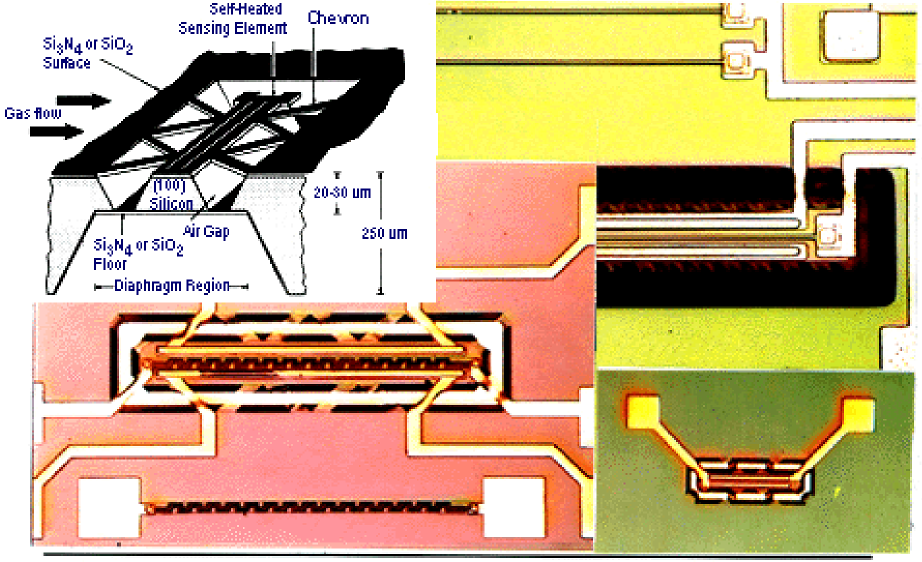
Microfluidics

Abstract-This paper presents the fabrication and test of a micropump, which can be attached to the Micro ELISA(Micro Enzyme-Linked Immunosorbent Assay) for the immunity test from a disease. The micropump consists of a pair of Al flap valves and a phase-change type actuator. The actuator is composed of a heater, a silicone rubber diaphragm and a working fluid chamber. The diaphragm is actuated by the vaporization and the condensation of the working fluid. The micropump is fabricated by the anisotropic etching, the boron diffusion and the metal evaporation. The forward and the backward flow characteristics of the flap valves illustrate the appropriateness as a check valve. Also, the flow rate of the micropump is measured. When the square wave input voltage of 8 V, 70 % duty ratio and 2 Hz is applied to the heater, the maximum flow rate of the micropump is 97 ul/min for zero pressure difference

Fund-This work was performed as a part of a Micro-ELISA Development Project was jointly sponsored by Micro/Nano System Integration Research Center and Korea Science & Engineering Foundation.

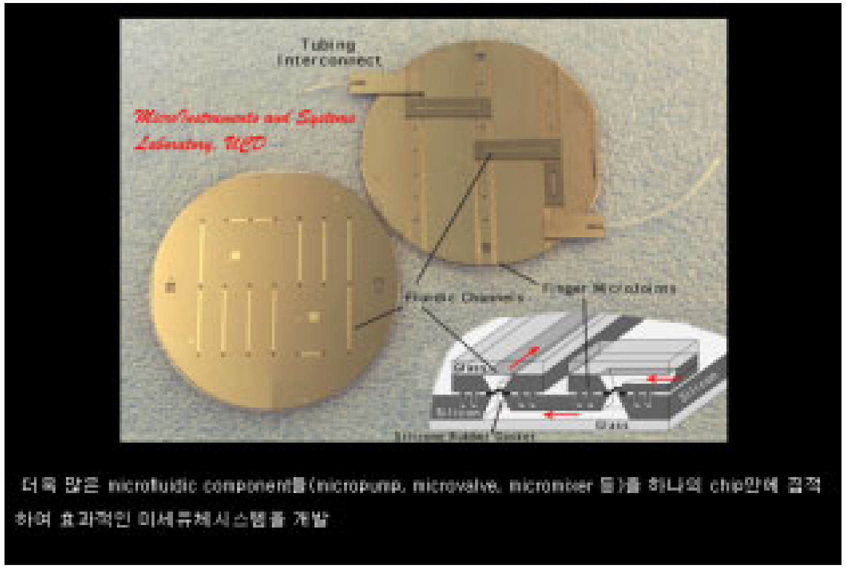


Micro Flow Sensors

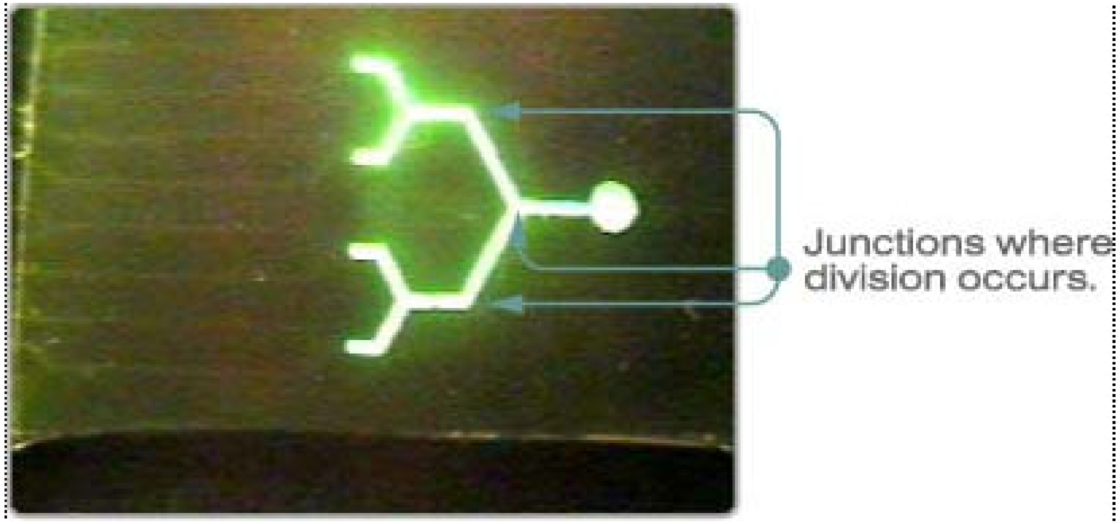


Center for Microelectronic Sensors and MEMS (CMSM)

Microfluidics



더욱 많은 microfluidic component들(micropump, microvalve, micromixer 등)을 하나의 chip안에 집적하여 효과적인 미세유체시스템을 개발


Junctions where division occurs.

Ice cream

Ingredients

butter fat 12%, sweetner 16%, milk solids nonfat 12%, emulsifier 0.3%, water 59.7%

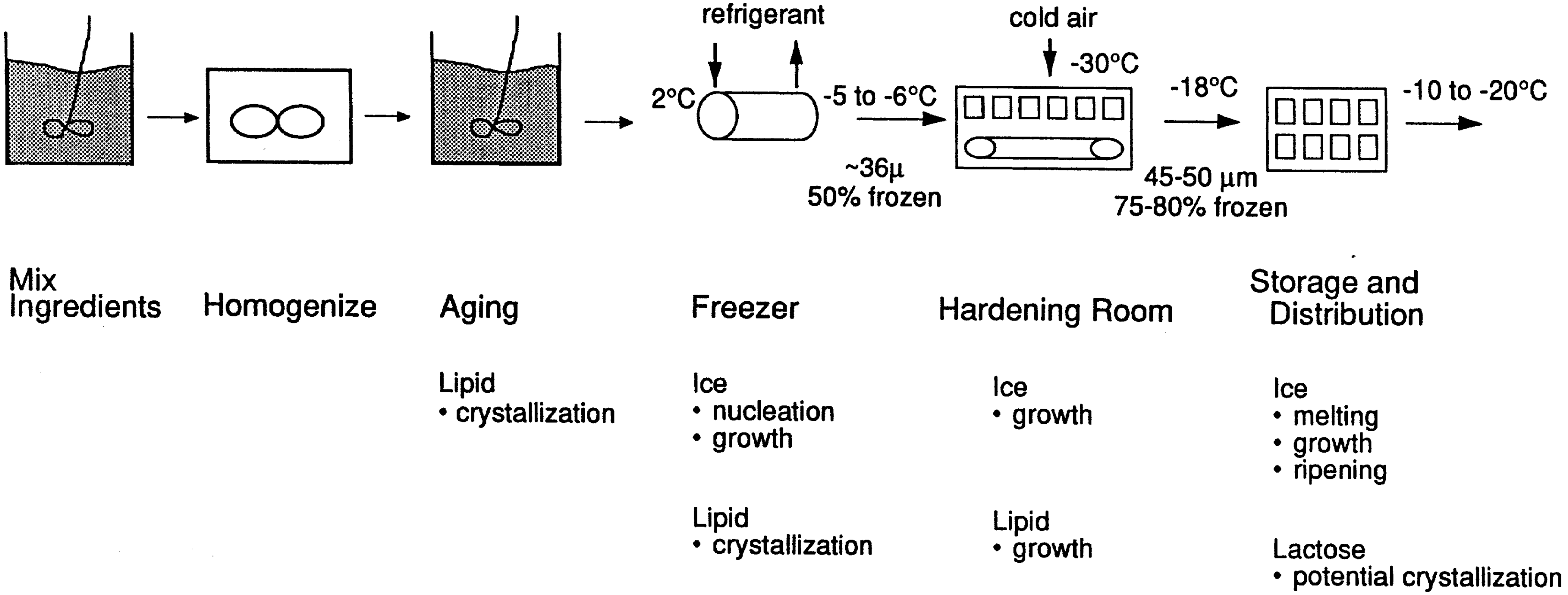


FIG. 12.1 Phase transitions during manufacture and storage of ice cream.

Ice cream

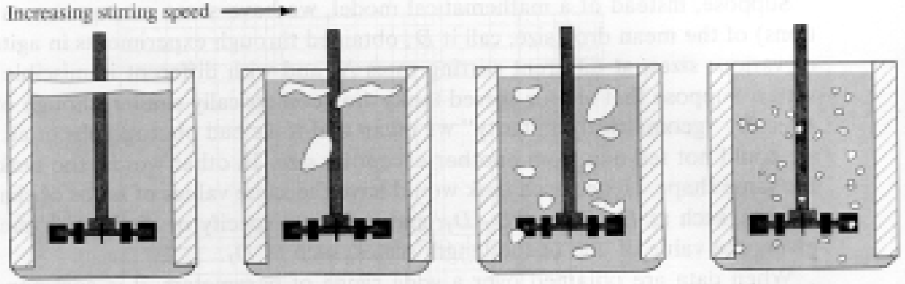


Figure 1.1.2 A light oil becomes increasingly dispersed as stirring speed increases.

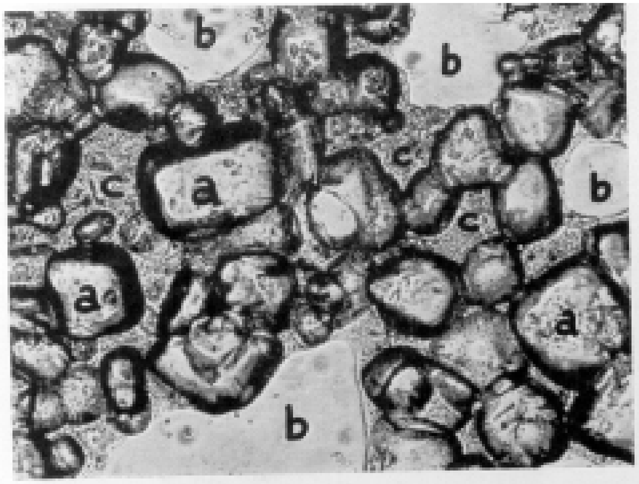


FIG. 12.4. THE INTERNAL STRUCTURE OF ICE CREAM

(a) Ice crystals—average size, 45 to 55 microns. (b) Air cells—average size, 110 to 185 microns. (c) Unfrozen material—average distance between ice crystals or ice crystals and air cells, 6 to 8 microns. Average distance between air cells—100 to 150 microns.

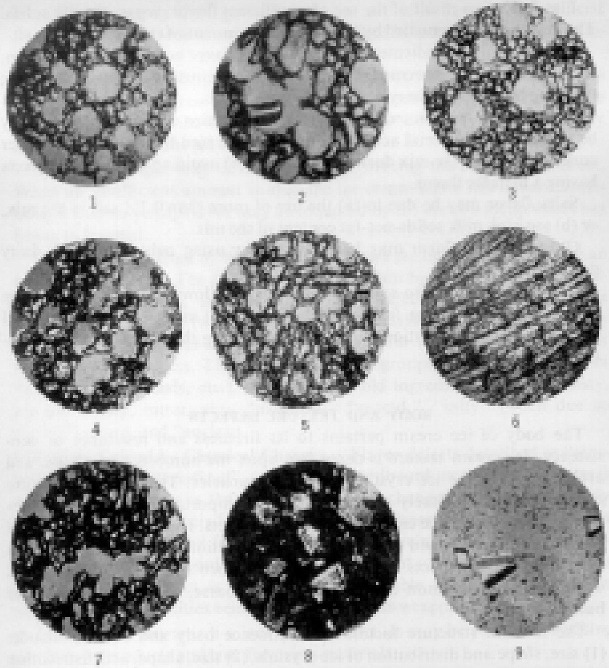


FIG. 17.1. PHOTOGRAPHS SHOWING BODY AND TEXTURE CHARACTERISTICS OF ICE CREAM

(1) Close, smooth, (2) coarse, open, (3) short, fluffy, (4) soggy, (5) coarse, icy, due to temperature fluctuation, (6) coarse, icy, flaky, due to slow freezing without agitation, (7) coarse, icy surface heat shock, (8) lactose crystals from sandy ice cream, (9) lactose crystals.

Chocolate

Ingredients

cocoa liquor 33%, sucrose 50%, cocoa butter 16%, lecithin 0.5%

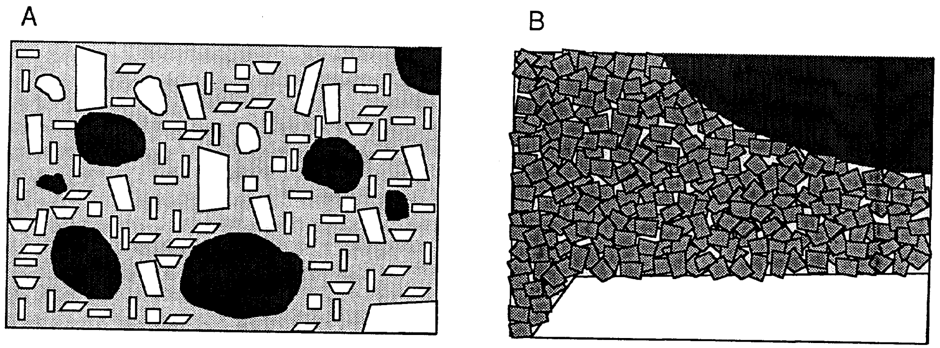


FIG. 8.2 Schematic representation of the structure of chocolate with cocoa solid particles in dark pattern and sucrose crystals in white. Lower magnification (A) shows the cocoa butter as a continuous phase. Higher magnification (B) shows that the cocoa butter forms discrete crystals in solid chocolate.

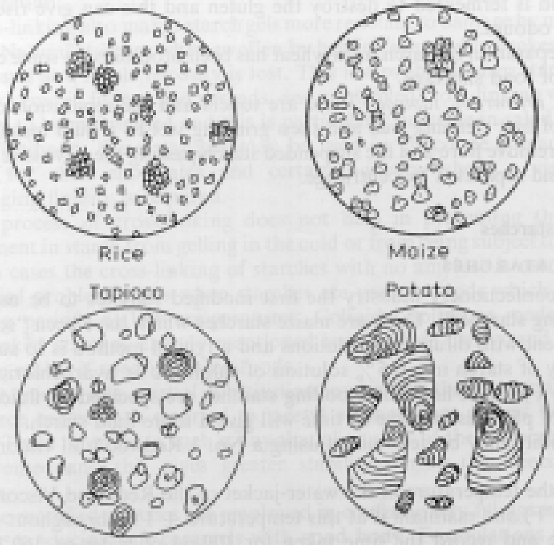


Fig. 13.1. Granule size—Rice 3–5μ, Maize 10–25μ, Tapioca 10–25μ, Potato 15–100μ. (Depends on origin.)

Extruder

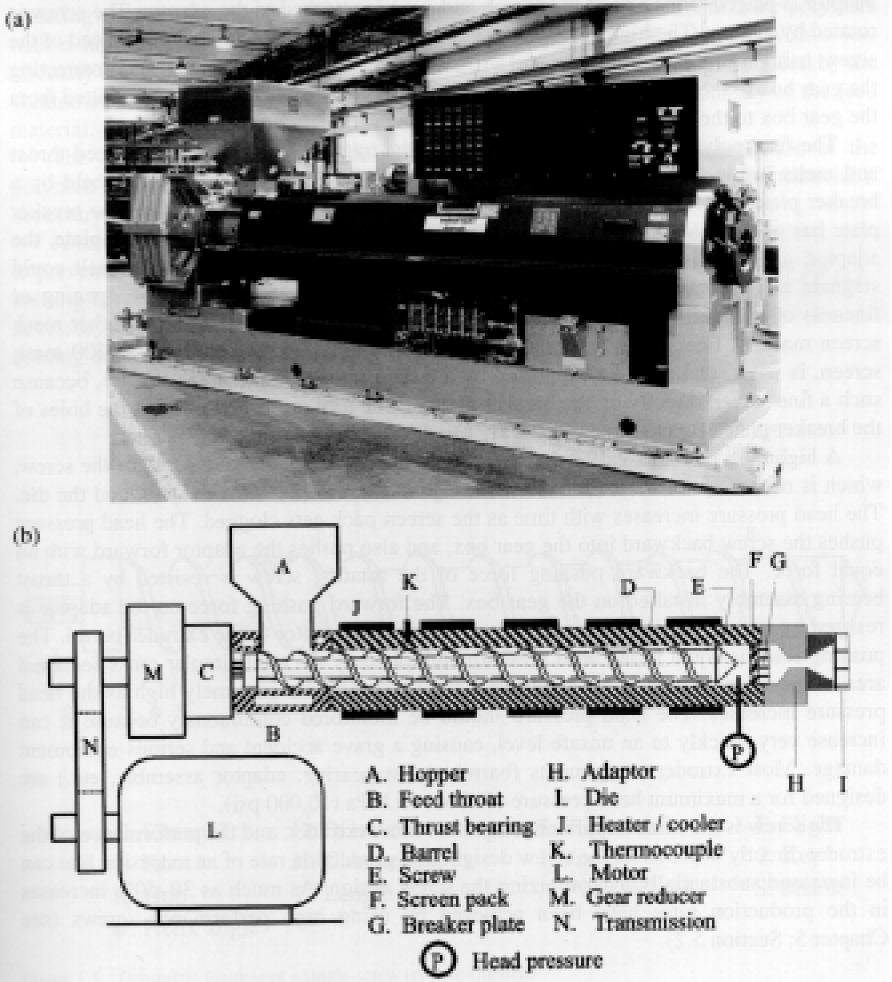


Figure 1.2 Single-screw extruder: (a) Picture of 114.3 mm (4.5 in) D, L/D = 30 extruder (courtesy of John P. Christiano, Davis-Standard Corp.); (b) Components of a typical extruder

Extruder (screw & screw channel)

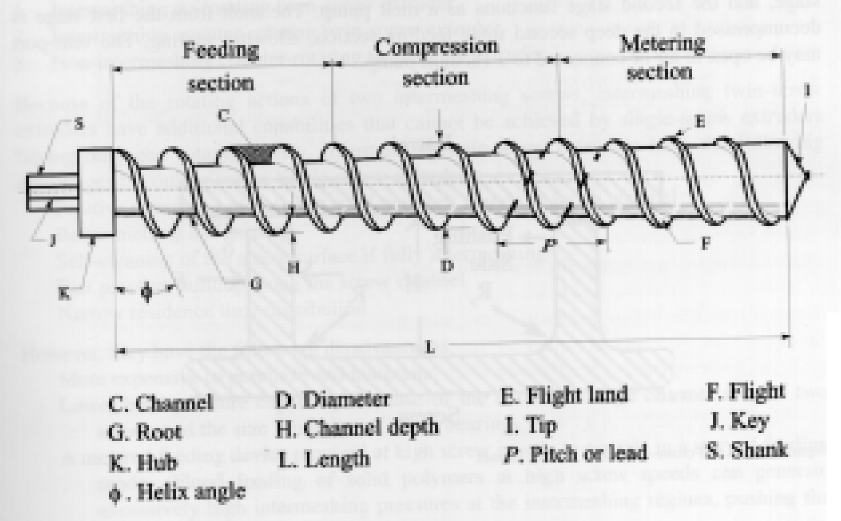


Figure 1.3 Geometric features of a single-screw (double-flighted)

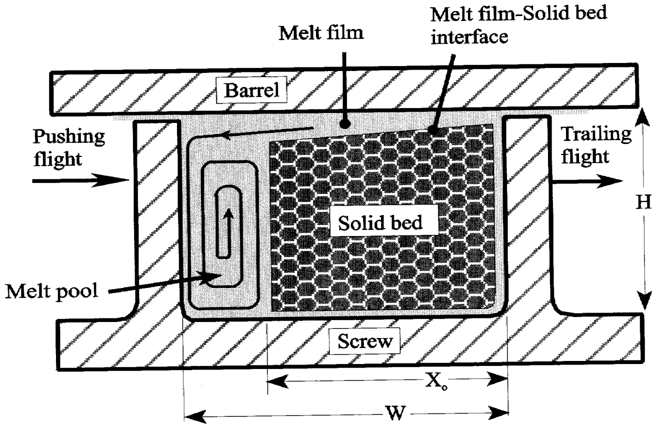
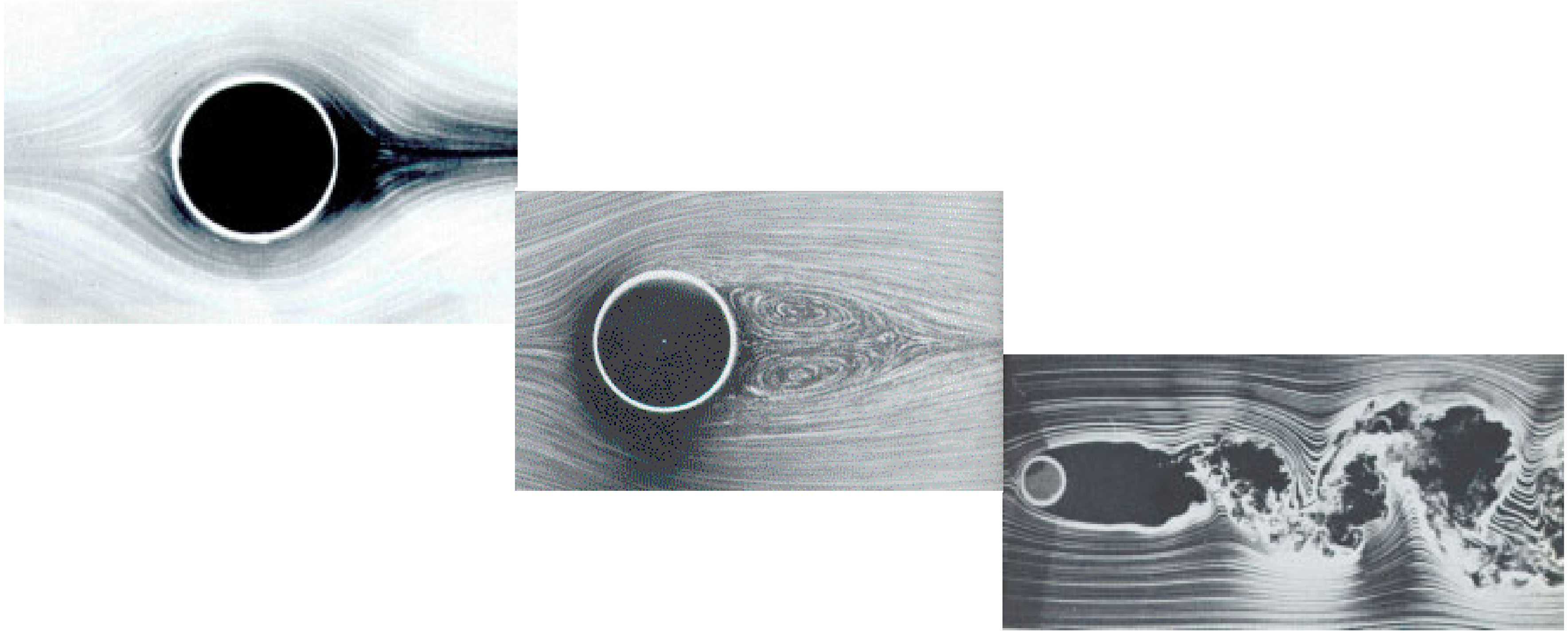
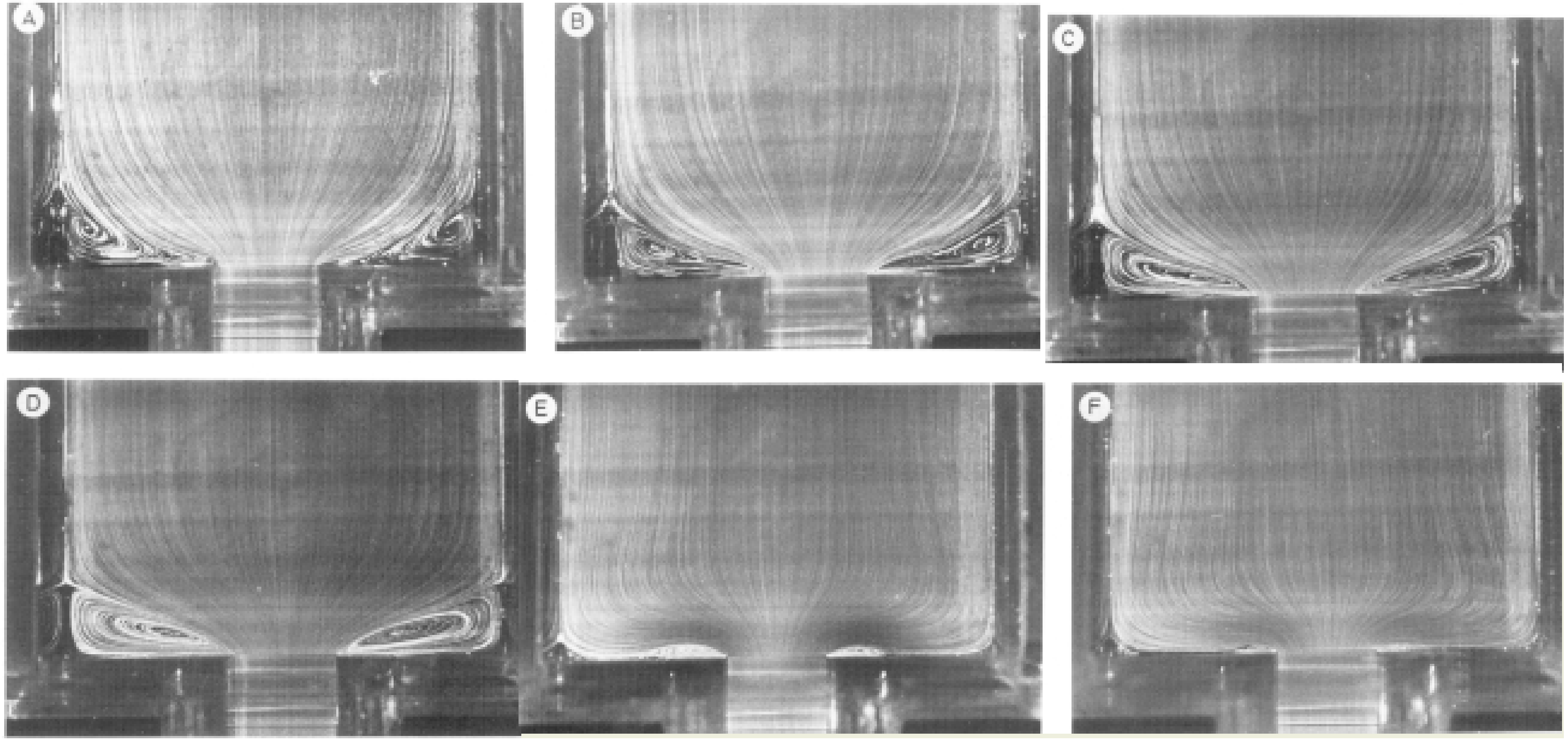


Figure 4.1 Idealized cross-section of screw channel perpendicular to flights containing solid bed and melt pool

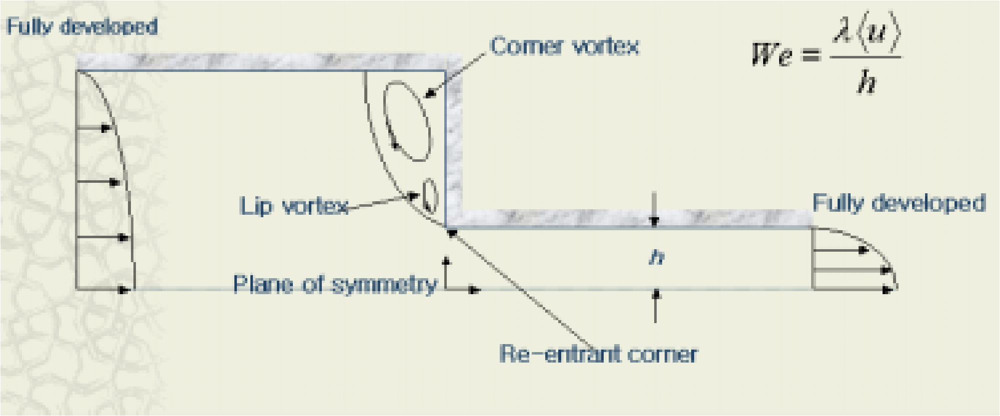
Fundamentals (flow around an obstacle)

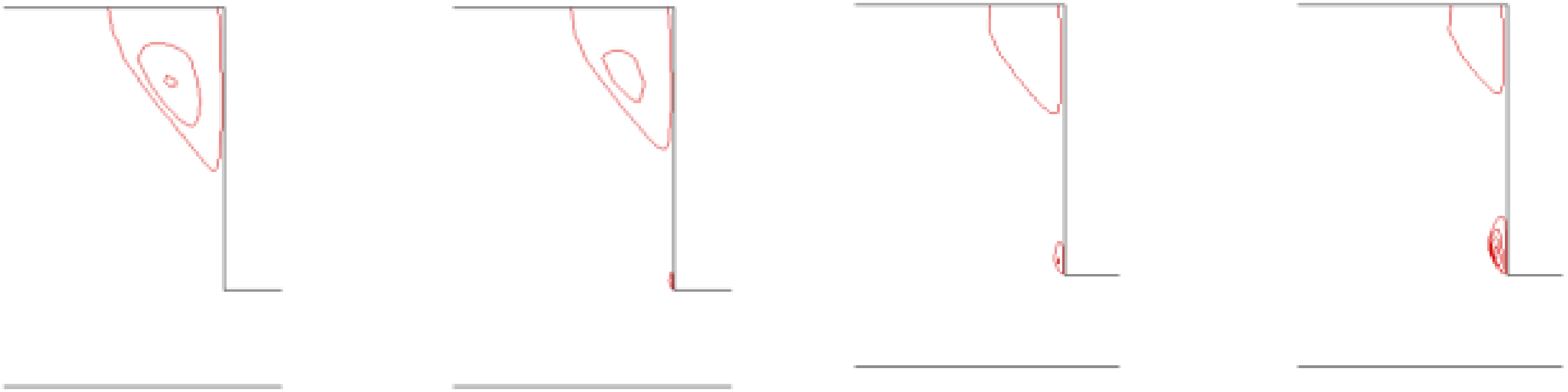


Contraction Flow



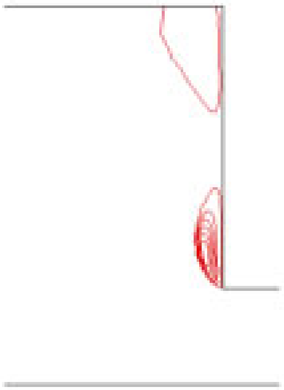
Contraction Flow

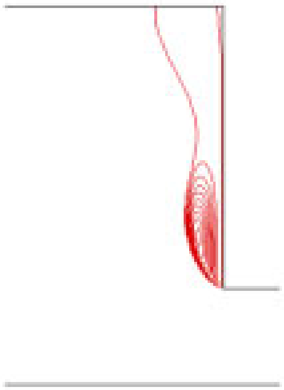


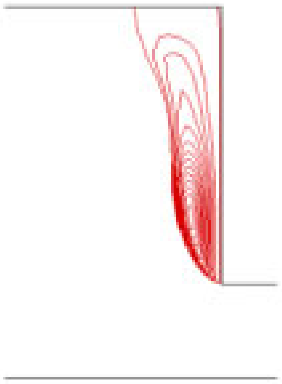


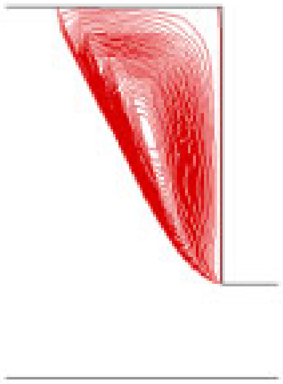
(a) Newtonian (b) *We*=1 (c) *We*=2 (d) *We*=3

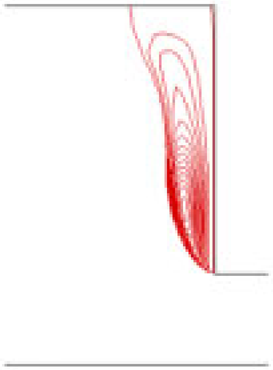
Contraction Flow

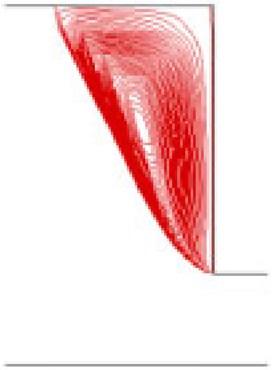

(e) *We*=4


(f) *We*=5


(g) *We*=6


(h) *We*=10


(g) *We*=6


(h) *We*=10

Drop Deformation

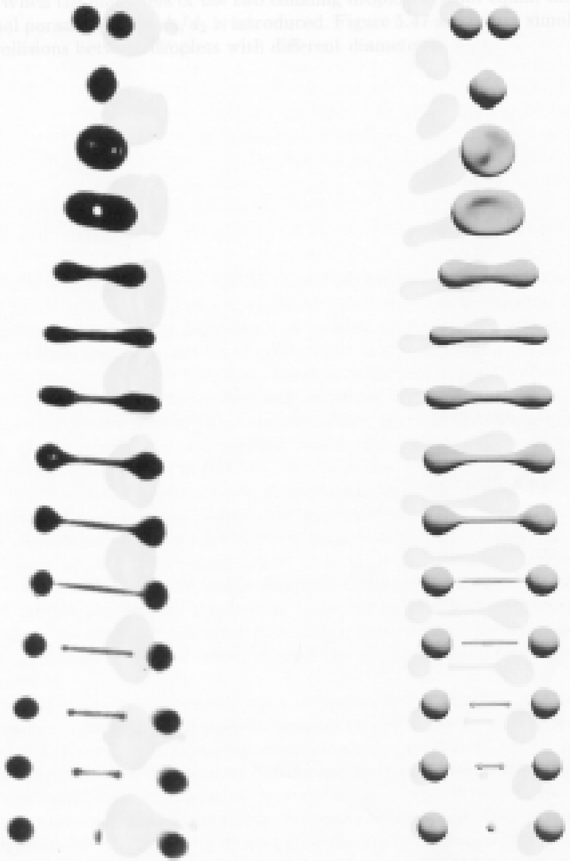
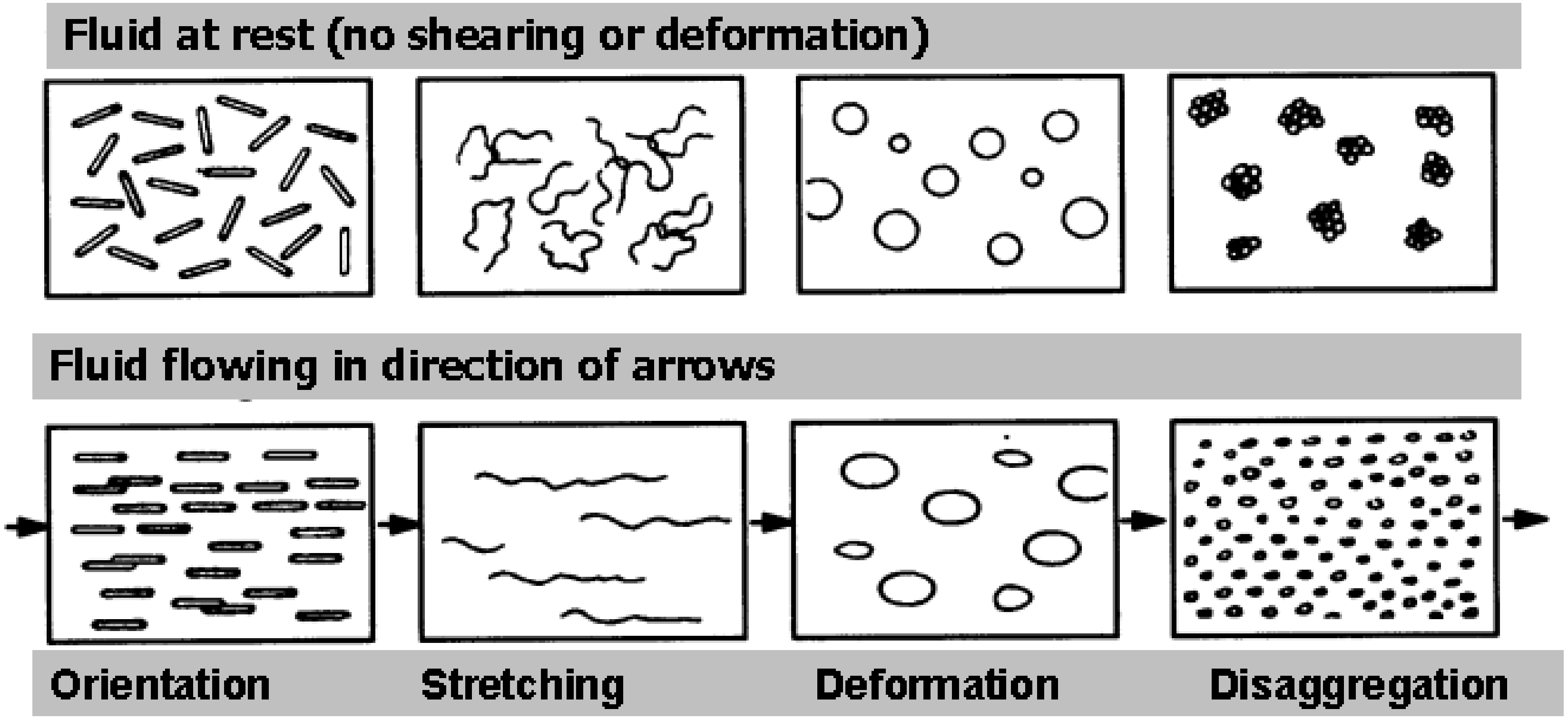


Fig. 5.46. Comparison of experimental result (left) and lattice Boltzmann simulation (right) of binary droplet collision with $We = 106$, $B = 0.5$, and $Re = 100$. The colliding droplets have the same size. The agreement between the droplet shapes obtained by experiment and simulation is very good (from M. Schelkle, ITLR)

Structure of Complex Fluids



Fluid at rest (no shearing or deformation)

Fluid flowing in direction of arrows

Orientation **Stretching** **Deformation** **Disaggregation**

Aggregation

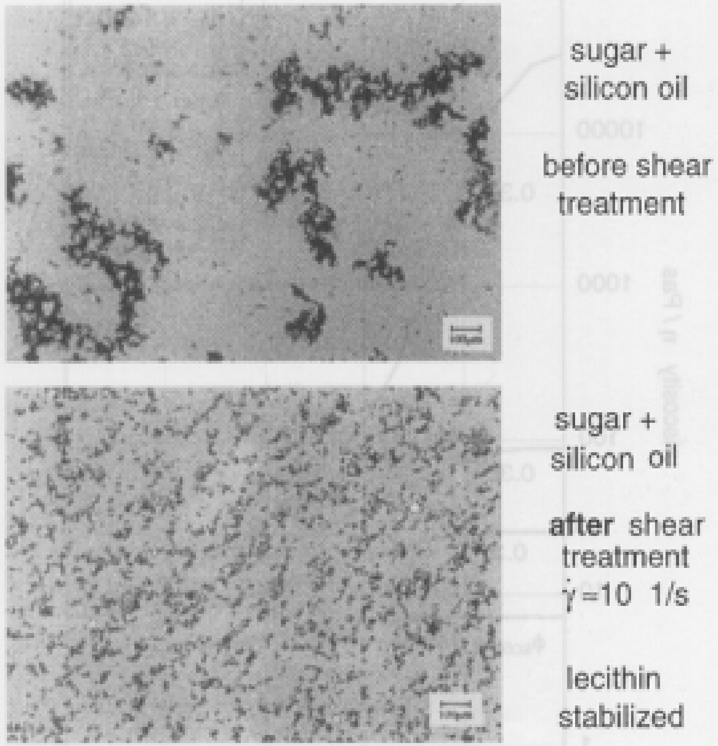


Fig.3 *Sugar aggregates in silicon oil (AK 1000) before and after shear treatment ($\gamma \approx 10$ 1/s); stabilisation with lecithin emulsifier; (16)*

Why Process Fluid Mechanics ?

Why Chemical Engineering ?

- Chemical Engineering is what chemical engineers do.
- material/process
- chemistry/physics/mathematics

Why Transport Phenomena

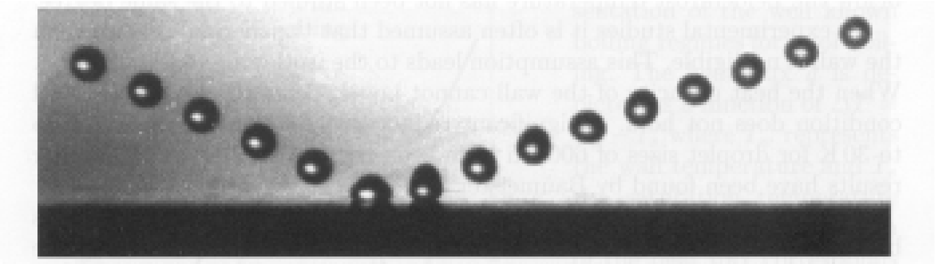
- fluid mechanics (momentum transfer)
- heat transfer
- mass transfer

Why Process Fluid Mechanics

- fundamentals
- industrial
- design
- modelling
- engineering sense
- insight for solving the physical problems

What is Fluid ?

solid / liquid / gas
elastic / viscous
Hookean solid / Newtonian fluid
non-Newtonian fluid
viscoelastic



Song of Deborah , Judges V.5
"The mountains flowed at the presence of the Lord,"

processing of water drop during the inverval of 10^{-15}sec

$$\text{Deborah number} = \frac{\text{characteristic time of the material}}{\text{characteristic time of the process}}$$

characteristic time of the material

water 10^{-12}sec , polymer 10^{-3} to 10^{1}sec , glass 10^{6}sec , mountain 10^{12}sec