Stratified Flows

In a multiphase stratified flow, the interfaces between immiscible fluids have several characteristics. Firstly, the specific interfacial area can be very large just as droplet-based flow. It can for example be about $10,000 \, \mathrm{m}^{-1}$ in a microchannel compared with only $100 \, \mathrm{m}^{-1}$ for conventional reactors used in chemical processes. Secondly, the mass transfer coefficient can be very high because of the small transfer distance and high specific interfacial area. It is more than 100 times larger than that achieved in typical industrial gas-liquid reactors. Thirdly, the interfaces of a stratified microchannel flow can be treated as nano-spaces. Simulation results show that the width of the interfaces of a stratified flow is in nanometers, and that diffusion-based mixing occurs at the interface. The interface width can be experimentally adjusted by adding surfactants. Finally, reactants only contact and react with each other at the interface. Therefore, the interfaces supply us with mediums to study interfacial phenomena, diffusion-controlled interfacial reactions and extraction.

The ideal 2D "nano-reactors" of the interfaces between immiscible fluids in stratified flows (Fig. 7b) have been used for chemical synthesis, triphase hydrogenation and biological enzymatic degradation, for extraction and separation, and for kinetic studies.

Future Directions for Research

Two-phase flows for a long time have been propelled by externally applied pressure, due to the inhomogeneity of two confined phases in the same system. High external pressure is needed to maintain flow in small devices due to the hydrodynamic resistance which increases with downscaling. This makes syringe pumping and vacuum pumping less suitable at smaller length scales. However, the capillarity-induced flow shows its importance at small flow dimensions. The capillary pressure is induced by interfacial forces which increase with downscaling. Moreover, more and more means have been found to modulate different interfacial forces of gas-liquid, gas-solid, liquid-liquid and liquid-solid. As device size decreases, the capillary pressure-driven flow therefore gains importance and may increasingly be used for systems where externally applied pressure would have to be extremely high.

Cross References

▶ Pressure-driven Flow
▶ Pressure-based Sample Injection
▶ Two-phase Flow

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Pressure Drop in Microchannels

▶ Turbulence in Microchannels

P

Pressure Injection

Definition

Pressure injection is another important technique for transferring sample to microfluidic chips.

Cross References

▶ Techniques for Transferring Samples to Chips

Pressure Measurements, Methods

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Synonyms

Pressure sensors

Definition

Experimentation and novel measurement techniques are crucial for the further development of microfluidic devices. Pressure is one of the basic parameters involved in microfluidic experiments. However, it is not realistic to apply conventional pressure measurement techniques to microsystems, since the characteristic dimensions of these measurement instruments are already comparable to those of the microdevices used. Therefore, novel pressure methods are needed for pressure measurement on the microscale.

Overview

It is not practical to measure pressures inside microchannels and nanochannels by use of conventional sensors, since it is very difficult or impossible to implement these sensors in microsystems without disturbing the flow field. Therefore, some novel methods are required for pressure measurement on the microscale.

The common practice for measuring the pressure drop along a microchannel is to use pressure transducers in the inlet and exit reservoirs, which gives overall information about the pressure rather than the pressure distribution along the channel. This approach is used in many studies related to fluid flow in microchannels [1–4].

Sekimori et al. [5] have developed a pressure sensor for use in Lab-on-a-Chip (LOC) devices. It has an embedded miniaturized structure and high chemical resistance, and causes no interference in the microflow during the measurement. This pressure sensor element has a volume of $1 \, mm^3$ and was fabricated by using MEMS technology. The pressure sensor element was installed in an LOC without any dead volume or disturbance to the microflow, and the pressure inside the microchannel was measured (see Fig. 1).

Wu et al. [6] proposed the use of single-walled carbon nanotubes (SWNTs) as nanoscale electromechanical pressure sensors. These authors demonstrated computationally a reversible pressure-induced shape transition in armchair SWNTs, which in turn induced a reversible electrical transition from metal to semiconductor. They also discussed the potential long lifetime of this pressure sensor due to the excellent mechanical durability of carbon nanotubes.

Li and Chou [7, 8] proposed the use of SWNTs as mechanical sensors to measure also mass, strain, and temperature, as well as pressure. The principle of sensing was based on the shift of the resonant frequency of a carbon nanotube resonator when it is subjected to changes in attached mass, external loading, or temperature. Li and Chou discussed the feasibility of such a sensor, with the aid of computer simulation using atomistic modeling together with molec-

Pressure Measurements, Methods, Figure 1 Installation of the pressure sensor to a microchip. Reprinted from [5] with permission from Dr. Kitamori

ular structural mechanics. They concluded that the sensing capability of this nanoscale sensor was superior to that of current microsensors, and that the sensitivity could be further enhanced by using smaller-sized carbon nanotubes.

Kim and Daniel [9] have recently suggested the use of atomic force microscopy (AFM) for measuring pressure profiles in micro/nanochannels. The method is based on measurement of the deflection of a thin plate over the channel surface by topographic imaging of the plate using AFM. Kim and Daniel verified this measurement technique numerically with artificially generated topographic data. Since the topographic imaging takes quite a long time, this technique is only applicable to steady-state processes. Moreover, special attention needs to be paid to providing vibration-free surroundings, since vibrations transmitted via the fluid can cause noise in the data, leading to loss of accuracy.

Matsuda et al. [10] have proposed the use of a pressure-sensitive paint (PSP) technique, which is based on the interaction of atoms or molecules with photons, to measure the pressure inside micro/nanochannels. This technique is limited to gaseous flow, and has drawbacks for high-pressure and low-speed applications. Moreover, the surface where the pressure is to be measured must be visible to the detector. The temperature sensitivity of the PSP technique must also be considered during the calibration.

In conclusion, although several techniques have been suggested by many researchers, the development of measurement techniques for use on the microscale is a challenging topic, and this topic seems likely to remain open-ended in the near future.

Cross References

► Nanofluidics in Carbon Nanotubes
► Control of Microfluidics

► Fluidic Nanosensors
► Velocity Sensors

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Pressure Sensors

► Pressure Measurements, Methods

Pressure Wave

► Shockwaves in Microchannels

Primitive Model

Synonyms

Element model

Definition

Primitive model is a single Differential–Algebraic Equation (DAE) derived from basic conservation laws in different domains describing the dynamic response of a constituent element (e.g., capacitors, inductors, resistors, channels, etc.) in a complex system.

Cross References

► Model Order Reduction (MOR)

Probe Microscopy

► Scanning Probe Microscopy

Programmed Cell Death

► Microfluidics for Studies of Apoptosis

Proper Orthogonal Decomposition (POD) Based MOR

Synonyms

Karhunen–Loève (K–L) expansion; Karhunen–Loève (K–L) decomposition; Karhunen–Loève (K–L) approach

Definition

Proper Orthogonal Decomposition is a technique that extracts the orthogonal basis function spanning the reduced subspace using an ensemble of data from experiments or numerical simulation of the original full systems.

P

Cross References

► Model Order Reduction (MOR)

Protein Adsorption

► Biomolecular Adsorption in Microfluidics

Protein Array

► Biochip
► Bioprinting on Chip

Protein Array and Cell Array

► Microarray