provide high resolution in generating nanochannels, they have some disadvantages, such as expensive facilities, high cost, instability leading to the low repeatability, and high time consumption, making the practical applications of nanoscaled RPS difficult.

Therefore, simple and reliable fabrication of nano-sensing channels, especially integrated with microchannels or the reservoirs, is still a critical issue and needs great research for the wide application of this technology.

Cross-References

- ▶ Electrical Double Layers
- ▶ Electrokinetic Flow and Ion Transport in Nanochannels
- ▶ Surface Conductivity

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Microfluidic Rotary Pump

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Synonyms

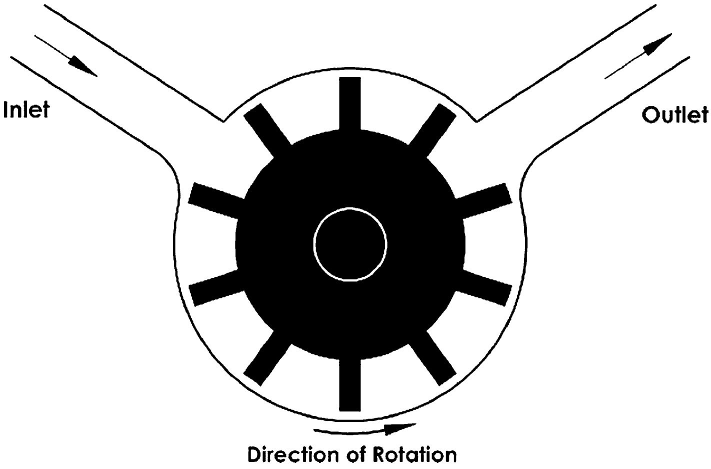
Microgear pump; Microlobe pump; Viscous micropump

Definition

Rotary micropump is a type of micropump which consists of a rotary element used for moving fluids. Based on different design concepts, rotary micropumps make use of either viscous forces or pressure forces to carry out the pumping action.

Overview

Conventional centrifugal or axial turbomachinery are not suitable for micro and nanoscales where Reynolds numbers are generally small, centrifugal and inertial forces are negligible, and viscous forces dominate the flow field (an excellent review can be found on the physics of microscale fluid flow in [1]). Many different types of micropumps have been proposed, developed and commercialized for microfluidics applications. Rotary micropumps make use of mechanical micro rotors to pump the fluid. Due to the dominance of viscous forces in micro scale, carrying out the pumping action by means of viscous forces is possible. A group of rotary micropumps operate on this concept [2, 3]. The other branch of rotary micropumps resembles its macro counterparts in the sense that it makes use of pressure forces to drive the fluid [4–14].



Microfluidic Rotary Pump, Fig. 1 Schematics of a general jet-type rotary micropump (Adapted from [3])

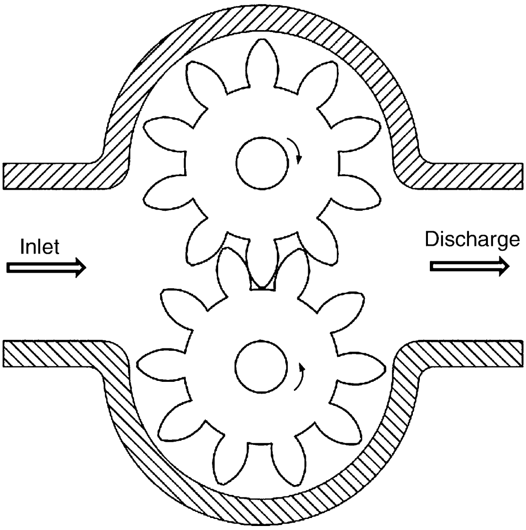
Basic Methodology

First attempts to miniaturize bulky pumps were started in 1990s. Sen et al. [2] first proposed the use of viscous forces in rotary micro-pumps and conducted some experiments for circular, square and rectangular cross-section rotors. Ahn and Allen [4] first designed and fabricated a jet-type rotary micropump which uses pressure forces for pumping. After these milestone research efforts, several groups investigated various configurations for rotary micropumps, however basics are the same.

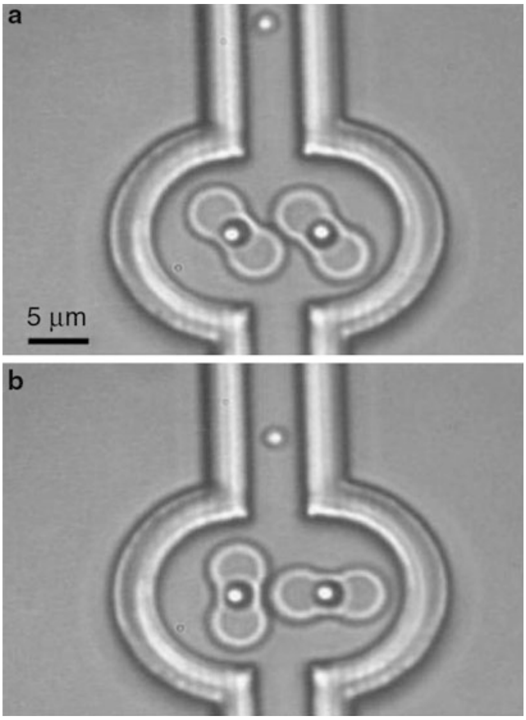
Key Research Findings

One of the earliest types of rotary micropumps developed for microfluidics applications, drug delivery in particular, is the jet-type magnetically driven fluid micropump. It is based on a rotary micromotor which is attached to a toothed rotor (Fig. 1). Basically, it is a micro version of conventional positive displacement pump. Flow rates up to 24 µL/min at a pressure of 10 kPa have been obtained using this design [4].

Microgear pump is a type of positive displacement pump which consists of two meshed microgears and housing (Fig. 2). Rotation of the gears forces tiny pockets of fluid to flow through the clearance between the pump and the housing. Matteucci et al. [5] has fabricated a magnetically actuated microgear pump having flow rates ranging from 0.5 mL/min to 8.5 ml/min at a maximum head of 100 cm-H_2O. Because of the magnetic coupling between the pump and the motor, potential for further miniaturization exists for this



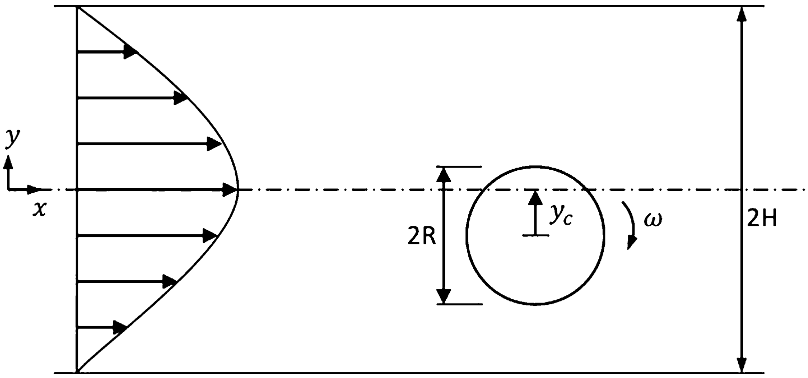
Microfluidic Rotary Pump, Fig. 2 Schematics of a general microgear pump design; nevertheless the need for an external motor to drive the external magnet limits the integration of the pump into a microchip. Also, as this micropump is positive displacement type, some flow pulsation should be expected.



Microfluidic Rotary Pump, Fig. 3 Microlobe pump in operation (Reprinted from [5] with permission from the author and the Journal of Applied Physics Letters)

To overcome the difficulty associated with having an external motor for the pump, an optically actuated microlobe pump has been developed. The pump consists of two lobes having diameters of 9 μm made from photopolymers. The lobes are actuated by time-divided scanning of a single laser beam. Figure 3 illustrates the lobes while the pump is in operation. Flow rates of less than 1 pl/min have been reported [6].

Another class of rotary micropumps makes use of the viscous stresses to pump the fluid. A micropump of this type, which is proposed by Sen et al. [2], is a device that is used for pumping fluids in microfluidic applications at extremely low Reynolds numbers. This miniature device consists of a rotating cylinder placed eccentrically inside a microchannel where the axis of the cylinder is perpendicular to the flow direction (See Fig. 4). Since it is placed asymmetrically inside the channel, there exists a viscous resistance difference between the small and large gaps between the cylinder and the channel walls (i.e. unequally distributed shear force on the upper and lower surface of the rotating cylinder), which causes a net flow along the channel. This pump is capable of pumping very small flow rates which is desired for many medical and biological applications such as drug delivery. The operation of this rotary pump depends on the viscous forces and it can operate in any situation where viscous forces are dominant. Therefore, it is suitable for



Microfluidic Rotary Pump, Fig. 4 Schematic drawing of a microfluidic viscous rotary pump pumping low viscosity liquids in micro ducts as well as highly viscous liquids such as heavy polymers in macro ducts. Together with its simplicity from the design point of view and the viscous nature of the pumping action which results in extremely low flow pulsation, this type of rotary pumps is suitable for scientific and industrial applications of MEMS (Micro-Electro-Mechanical-Systems), NEMS (Nano-Electro-Mechanical-Systems) and LOC (Lab-on-Chip) technologies.

The channel height, eccentricity (i.e. degree of asymmetry, $\varepsilon = y_c/(\text{H-R})$, see Fig. 4), Reynolds number, channel cross-section and the angular velocity of the rotating cylinder affect the performance of the pump. These effects have been extensively studied by many researches [2, 7–12]. 2D, steady [7] and transient [8, 9], and 3D, steady [10] numerical analysis of this rotary pump concept is studied for circular as well as the square and rectangular [9] cross-sectional rotors. Thermal effects due to viscous dissipation on pump performance are also analyzed by considering the temperature dependent fluid properties [11]. Closed form, analytical expressions for the flow rate and pressure drop along the channel are derived by using lubrication approximation [12]. The effect of slip-flow boundary condition is also investigated [7]. Another interesting application of this design is proposed by DeCourtye et al. [10] as a microturbine which can be used as a microsensor for measuring exceedingly small flow rates in micro/nanofluidics applications.

Blancard et al. [3] proposed a new type of viscous micropump which uses rotational movement of disks instead of an eccentric rotor. In this concept, fluid is either on one disk or is sandwiched between two disks while the viscous stresses induces by the rotation of the disk(s) drives the flow. Maximum flow rates of 1.0 ml/min for the single-disk and 2.1 ml/min for the double-disk micropumps have been achieved.

Peristaltic rotary pump is a type of positive displacement pump which induces flow by means of peristalsis. A metering rotary peristaltic pump has been developed which overcomes the shortcoming related to flowrate control which is generally associated with peristalsis-based pumping. This design consists of a set of PDMS microchannels wrapped around a camshaft. The rotation of the cam induces peristaltic flow. Flowrates ranging between 15 nL/min and 1 μL/min have been achieved. Advantages of this design include ease of manufacturing, precise flow control and durability. This micropump has built-in features that regulate pulsatility of flow, which gives this pump

Microfluidic Rotary Pump, Table 1 Summary of the specifications of the different rotary micropumps discussed in this entry

References	Type of rotor	Type of actuation	Pressure head	Flow rate
[2]	Circular/square/ rectangular	Mechanical/external	NA	NA
[3]	Single-disk	External DC motor	643 Pa	1.0 ml/min (max)
[3]	Double disk	External DC motor	1.19 kPa	2.1 ml/min (max)
[4]	10- poles/jet type	Magnetic	100 hpa	24 μl/min
[5]	Micro-gears	Magnetic	100 cm-H_2O	0.5–8.5 ml/min
[6]	Micro-lobes	Optical	NA	1 pl/min
[12]	Double disk	External DC motor	1.19 kPa	2.1 ml/min (max)
[13]	Cam shaft/ peristaltic	Miniature stepper motor	Up to 5 PSI	15 nl/min – 1.0 μL/min
[14]	Annualar gears	DC – stepper motor	1.5–150 bar (different models)	1 μL/h – 1 L/min (different models)

a unique advantage in comparison with other peristaltic designs [13].

More recently, HNP Mikrosysteme GmbH [14] has commercialized a type of rotary pump called micro annular gear pump. This type of pump is a positive displacement pump with an externally toothed rotor and internally toothed ring, which are assembled with a small eccentricity of their rotation axes with respect to each other. The rotation of the internal rotor forces the fluid pockets which are interlocked between two gears to flow. The pump flow rates vary from product to product, but are in a range of 1 μL/h to 1.2 l/min. Advantages of this product include accurate control of flow rate and minimum pulsation in delivery.

The specifications of the micropumps described in this entry are summarized in Table 1.

Precise control of the fluid flow inside microchannels is an important issue for the development of the microfluidics technology. Microfluidic rotary pumps with different configurations serve as subtle solutions to control the flow in microfluidic devices, and will contribute to the development of the microfluidics technology.

Future Directions for Research

Several different mechanisms and configurations have been exploited in the recent years to enhance the performance of the rotary micropumps and to make them more compact. In the coming years, work on the full integration of the micropumps on the chip will continue. This essentially requires minimizing the number of moving parts and eliminating all the bulky parts including external power units. Also, improving the transient response and flow control of these pumps is highly desirable as this class of micropumps will come up as a main candidate for the future drug delivery and monitoring (e.g. Automatic insulin infusion and blood glucose monitoring) systems.

Cross-References

- ▶ Centrifugal Microfluidics
- ▶ Magnetic Pumps
- ▶ Piezoelectric valves
- ▶ Thermocapillary Pumping

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