should not be considered as limiting the invention to any of the parameters associated with any of the system embodiments disclosed herein or any particular theory of operation.

[0149] In general, inertial lift forces in laminar microfluidic systems, such as those described in the embodiments herein, can act to focus randomly distributed particles continuously and at high rates into a single streamline. Particle geometry dependence can be used to develop systems for high-throughput separations. Channel geometry can be changed to reduce focusing particles from an annulus to four points, to two points, and then to a single point within the channel. Two additional levels of particle ordering can be observed, in particular, longitudinally along the channel length and rotationally (for asymmetric particles). In general, separation, ordering, and focusing is primarily controlled by a ratio of particle size to channel size and the flow characteristics of the system. Advantageously, the focusing is independent of particle density.

[0150] Lateral migration of particles in shear flow arises from the presence of inertial lift, attributed mainly to the shear-gradient-induced inertia (lift in an unbounded parabolic flow) that is directed down the shear gradient toward the wall, and the wall induced inertia which pushes particles away from the wall. Particles suspended in fluids are subjected to drag and lift forces that scale independently with the fluid dynamic parameters of the system. Two dimensionless Reynolds numbers can be defined to describe the flow of particles in closed channel systems: the channel Reynolds number (R_c), which describes the unperturbed channel flow, and the particle Reynolds number (R_p), which includes parameters describing both the particle and the channel through which it is translating.

$$R_c = \frac{U_m D_h}{v}$$

and

$$R_p = R_c \frac{a^2}{D_h^2} = \frac{U_m a^2}{vD}$$

[0151] Both dimensionless groups depend on the maximum channel velocity, U_m, the kinematic viscosity of the fluid, and $\nu=\mu/\rho$ (μ and ρ being the dynamic viscosity and density of the fluid, respectively), and D_h, the hydraulic diameter, defined as 2wh/(w+h) (w and h being the width and height of the channel). The particle Reynolds number has an additional dependence on the particle diameter, a. The definition of Reynolds number based on the mean channel velocity can be related to R_c by $R_e=2/3\ R_c$.

[0152] Inertial lift forces dominate particle behavior when the particle Reynolds number is of order 1. Typically, particle flow in microscale channels is dominated by viscous interactions with $R_p<<1$. In these systems, particles are accelerated to the local fluid velocity because of viscous drag of the fluid over the particle surface. Dilute suspensions of neutrally buoyant particles are not observed to migrate across streamlines, resulting in the same distribution seen at the inlet, along the length, and at the outlet of a channel. As R_p increases, migration across streamlines occurs in macroscale systems. In a cylindrical tube, particles were observed to migrate away from the tube center and walls to form a focused annulus. The theoretical basis for this "tubular pinch" effect is a combination of inertial lift forces acting on particles at high particle Reynolds numbers. The dominant forces on rigid particles are the "wall effect," where an asymmetric wake of a particle near the wall leads to a lift force **60** away from the wall, and the shear-gradient-induced lift force **62** that is directed down the shear gradient and toward the wall, as shown in FIGS. **5**A and **5**B. A relation describing the magnitude of these lift forces (F_z) in a parabolic flow between two infinite plates is useful in understanding how the intensity of inertial migration depends on system parameters with the caveat that the derivation assumes $R_p<1$.

$$F_z = \frac{\rho U_m^2 a^4}{D_h^2} f_c(R_c, x_c) = \frac{\mu^2}{\rho} R_p^2 f_c(R_c, x_c)$$

[0153] Here $f_c(R_c, x_c)$ can be considered a lift coefficient and is a function that is dependent on both the position of the particle within the cross-section of the channel x_c and the channel Reynolds number, but independent of particle geometry. At the equilibrium position, where the wall effect and shear-gradient lift balance, $f_c=0$.

[0154] Inertial lift acting on a particle leads to migration away from the channel center. From the equation for F_{lift}, an expression for the particle migration velocity, U_p, can be developed assuming Stokes drag, $F_s=3\pi\mu a U_p$, balances this lift force:

$$U_p = \frac{\rho U_m^2 a^3}{3\pi\mu D_h^2} f_c(R_c, x_c)$$

[0155] An estimate of the transverse migration velocity out from the channel center line can be made by using an average value of $f_c\sim0.5$ for flow through parallel plates. This calculation yields a value of 3.5 cm/s for 10-μm particles in a flow with $U_m=1.8$ m/s. Traveling a lateral distance of 40 μm requires traveling ~2 mm downstream in the main flow. The previous equation for U_p also indicates that the lateral distance traveled will depend heavily on particle diameter, indicating the possibility of separations based on differential migration.

[0156] Channels with curvature create additional drag forces on particles. When introducing curvature into rectangular channels, secondary flows develop perpendicular to the streamwise direction due to the nonuniform inertia of the fluid. In a parabolic velocity profile, one example of which is shown in FIG. **6**A, faster moving fluid elements within the center of a curving channel can develop a larger inertia than elements near the channel edges. These elements can move toward the channel outer edge, and in order to conserve mass at all points

$$\left(\nabla \cdot \rho\vec{V} + \frac{\partial \rho}{\partial t} = 0\right),$$

the fluid is recirculated along the top and bottom of the channel. Two dimensionless numbers can be written to characterize this flow, the Dean number (D_e) based on the maximum velocity in the channel, and the curvature ratio (δ). The Dean number, $D_e=R_c(D_h/2r)^{1/2}$ and the curvature ratio, $\delta=D_h/2r$, where r is the average radius of curvature of the channel. For