Using particle collisions for mixing and dispersion

A new way to break up particles in liquids

Robert P. Bruno, V.P. Sales & Marketing
Microfluidics International, Newton, MA

Over the last decade, researchers have made significant progress in reducing particles into uniform submicron sizes and dispersing them uniformly in a liquid, a process known as high-performance mixing and dispersion.

Applications include emulsification, dispersion, homogenization, cell rupture, encapsulation and deagglomeration. For example:

- If carbon particles (ink pigment) can be made small enough and a stable dispersion is created, the ink can be propelled through tiny jets, making the high-resolution, ink-jet printer possible.
- If drug molecules can be encapsulated within liposomal vesicles, the drug can be administered at a lower dosage with less toxicity and more precise targeting inside the human body—thereby reducing both costs and potential side effects.
- If biological cells can be broken open without destroying the compounds

Fig. 1. Principle of operation.

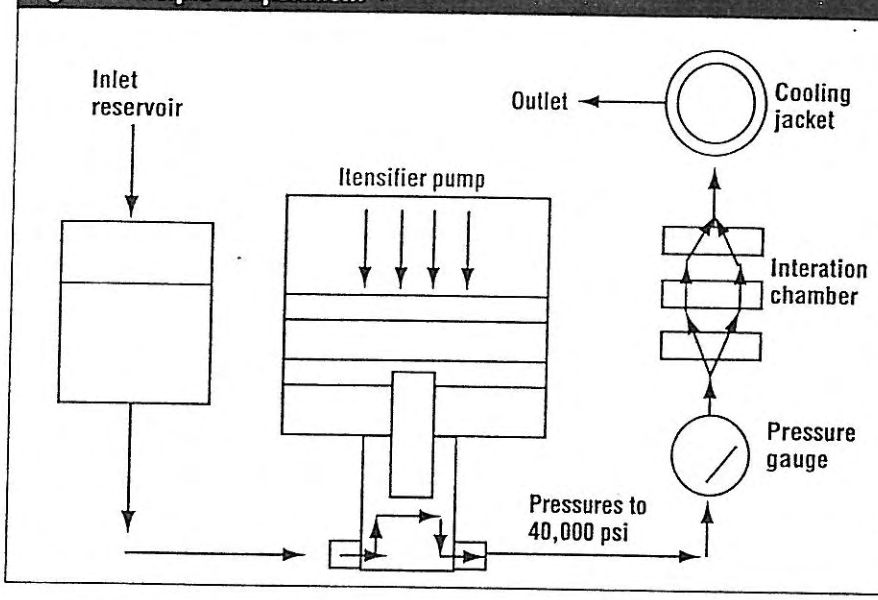


Fig. 1. A fixed geometry of the interaction chamber guarantees the entire process stream is subjected to identical energy forces. These powerful forces include shear, impact and cavitation, leading to consistent, uniform and reproducible results.

Fig. 2. Double-acting intensifier pump.

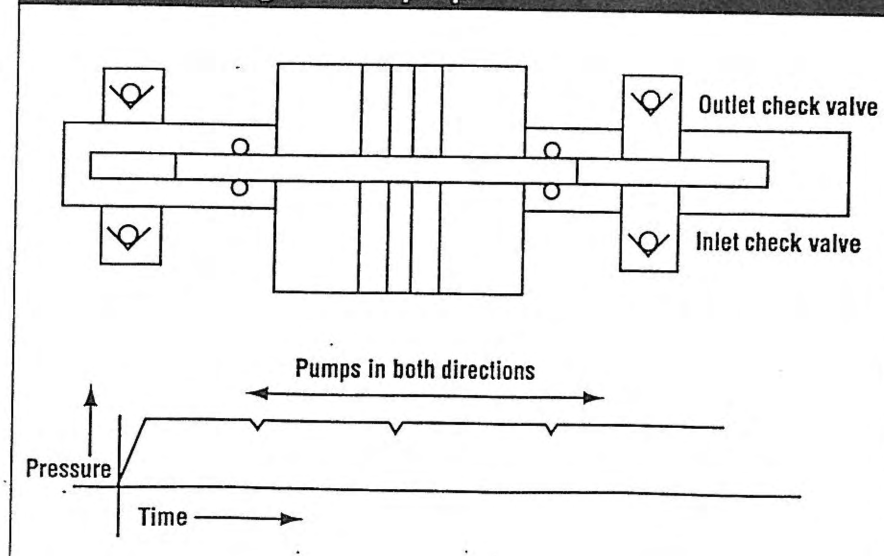


Fig. 2. A major difference between intensifier and conventional pumps is the actuation of pressure during the pumping cycle. Intensifier pumps deliver near-optimum, almost-constant pressure throughout the cycle compared to conventional pumps, which experience a pressure "dip" as the pump sucks in new fluid to pump.

inside, these living organisms can be used as factories for producing new drugs.

- If fat globules in milk products can be made small enough, the fat content can be reduced while the taste improves and product stability and shelf life increase.

These are just some of the achievements of high-performance mixing and dispersion. Others include sharper display screens, high-density data disks and clear sunscreen lotion.

While all of these products were being introduced in recent years, only one new way to break up particles in liquids has been developed—the use of controlled high-speed collisions between particles.

Collision technology does what homogenizers, grinding mills and other traditional equipment have done for more than a century. The difference is that many formulations that were not possible or not economical with conventional techniques are being produced with particle-collision technology.

Characteristics of particle-collision technology include:

- Smaller particle and droplet sizes;
- More uniform particle size distribution;
- Faster processing times (greater than two orders of magnitude in some applications);
- Better control of the amount of energy applied;
- Much higher energy (up to 40,000 psi sustained);
- Scalability from small batches to continuous production;
- No moving parts in the patented interaction chamber;
- Little or no contamination of product being produced;
- Uniform dispersions and emulsions;
- Highly repeatable process from run to run.

Technology overview

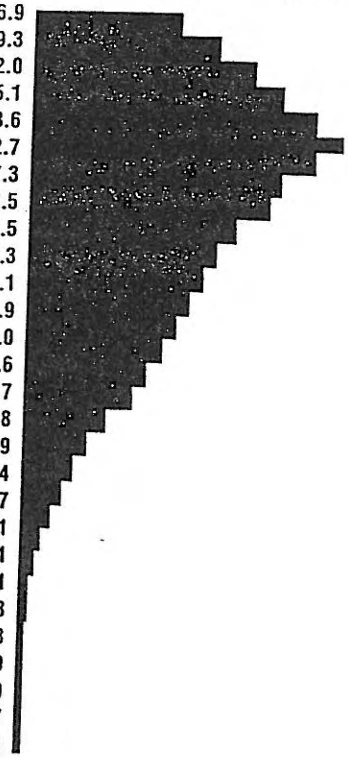
The basic principle behind particle-collision technology is the bombardment of a colloid system or fluid stream against itself inside an interaction chamber of fixed geometry and at very high energy.

How much energy? By applying 20,000 psi of energy to a waterlike material, particle-collision technology achieves 2×10^7 watts per kg of energy dissipation within fixed geometries measured in sizes of human hair diameters.

All of this mechanical energy results in the breakup and dispersion of the slurry. None of the energy is wasted. All product components experience the same high force in the same small area, resulting in extremely small particle sizes and a narrow particle size distribution.

With particle-collision technology, no grinding media, mixing blade, or homogenizer valve is required because size is reduced by:

- Crushing forces of the particles hitting themselves;
- Shear forces on the particles within



Diameter (nanometers)	Volume: Relative	Percent
16.9	0.407	3.321
19.3	0.515	4.204
22.0	0.629	5.136
25.1	0.741	6.053
28.6	0.843	6.884
32.7	0.925	7.552
37.3	0.979	7.994
42.5	1.000	8.164
48.5	0.985	8.044
55.3	0.937	7.647
63.1	0.859	7.014
71.9	0.760	6.206
82.0	0.649	5.299
93.6	0.535	4.365
106.7	0.425	3.469
121.8	0.326	2.660
138.9	0.241	1.968
158.4	0.172	1.404
180.7	0.118	0.967
206.1	0.079	0.643
235.1	0.050	0.412
268.1	0.031	0.255
305.8	0.019	0.152
348.8	0.011	0.088
397.9	0.006	0.049
453.9	0.003	0.026
517.7	0.002	0.013
590.5	0.001	0.007
673.5	0.000	0.003
768.2	0.000	0.002

Dispersion after processing
One pass at 18-20 kpsi
- Starting particle, size: 2122.2 nm
- Ending particle, size: 5.7 nm

* Mean diameter

Fig. 3. Particle size distribution produced by collision technology. The unique design of the intensifier pump and interaction chamber yields remarkably narrow particle size distribution, making the process ideal for applications such as pharmaceuticals where high uniformity of results are a requirement.

the interaction chamber;

- Cavitational forces due to extreme velocity changes in the material stream.

As shown in Fig. 1, particle-collision technology pressurizes a fluid stream, develops high-velocity stream(s), and then smashes these against each other within the interaction chamber. The energy applied to the product can be changed by changing the pressure on the fluid stream—to accommodate more viscous liquids, perhaps, or to create a more intense mixing or dispersing action.

The geometry of the jet paths within the interaction chamber remains constant. Therefore, all particles experience the same forces, and the smallest size and the most uniform size distribution of any of the high-performance mixing processes are achieved.

Besides the fixed geometry of the interaction chamber, another factor that ensures uniform particle size is the type of pump used, which is called an "intensifier pump." This pump can be driven by air or hydraulic fluid. The intensifier pump's advantage is that it can pump the product, even viscous systems, through the fixed geometry interaction chamber at constant pressure. The pressure can be incrementally and accurately increased or decreased over a wide range simply by adding or subtracting pneumatic or hydraulic power.

Yet, even though intensifier pumps can be set to a broader range of pressures than conventional pumps, once set their pressures stay constant over the entire process stroke (Fig. 2).

Another factor that contributes to the intensity range of the particle-collision technology is the overall architecture of the process itself. Breaking the stream in two and redirecting the streams to impinge upon themselves doubles the relative velocity with which particles impact each other.

Added to the force of this impact are the cavitational forces created by the sudden increase in velocity within the interaction chamber. This sudden increase in velocity results in a sudden decrease of pressure in the channels, creating bubbles that collapse on themselves. This is cavitation. There are also shear forces acting within the passages at very high speeds.

Traditional methods

One way to understand particle-collision technology is to compare it with more traditional methods for reducing particle size. A grinding mill is the oldest and most widely used and, therefore, best-understood method of reducing particle size for materials to be dispersed.

In a grinding mill, the material (a liquid, slurry or powder) to be processed is combined with media such as ceramic beads. As the mill rotates, the beads grind the material into smaller and smaller particles. Grinding mills have been used for decades and the basic technology has remained the same.

Limitations of grinding mills include:

- Contamination of the product by the grinding media;
- Difficulty of scaling the process;
- Lack of control of the amount of energy applied;
- Large batches require large (room-size or bigger) mills;
- Very long processing times required to achieve small particles;
- High support requirements (cleaning, setting up and extracting the media).

Another alternative to particle-collision technology is homogenizer valves, which push fluids through a variable geometry spring-loaded valve.

Like mills, homogenizers have been used for many years. They offer simplicity of operation and reliable service (at pressures typically below 10,000 psi).

Their main drawback is limited particle size reduction, but they work for applications requiring high-volume throughput at low pressures, such as milk homogenization at 2,000 psi to 3,000 psi.

A limitation of homogenizers is the spring-actuated valve controlling the orifice size in response to the size of the particles passing through. This creates two potential problems: particle (or droplet) size is allowed to vary, and the process pressure is limited.

With particle-collision technology, particle size is more consistent (and can be much smaller) than achieved with conventional homogenizers (Fig. 3). That is because particle-collision technology can apply sustained pressures of up to 40,000 psi compared to a standard homogenizer's 10,000 psi to 12,000 psi.

Uniform particle size

Constant pressure uniformly applied yields particles of uniform size distribution. High pressure, high velocity, and a variety of forces all working at once on the same fluid stream yield very small particles. A very broad pressure range (up to 40,000 psi) opens a wide variety of applications and materials to the advantages of small and uniform particle size distribution.

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These are the main advantages of particle-collision technology and often the main advantage manufacturers look for when selecting technology to emulsify, deagglomerate, disperse or disrupt cells.

But there are other advantages that result as inherent by-products of this new way to break down and mix materials:

The principles that allow particle-collision technology to work do not change whether the equipment is large or small—meaning that an application that has been proven on a small machine can be switched to incrementally larger machines as the market for that application grows.

Additional advantages are lower processing cost, increased speed of operation and more flexible manufacturing capability in the face of evolving market opportunities.

■ To receive more information on the Microfluidizer® Processor—Microfluidics International Corp., Newton, MA. CIRCLE 401