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# An introduction to centrifugal cleaners

## Scope

The purpose of this Technical Information Paper is to introduce the reader to centrifugal cleaners, from basic theory of operation to operational issues. Specifically, high density, forward, and lightweight cleaners are presented along with their purpose in stock preparation.

## Safety

Before operating a cleaner system, the reader should review the following safety guidelines:

- Always lock out all pumps associated with a cleaner system before removing any cleaners for maintenance. Do **NOT** attempt to disassemble any portion of a cleaner during operation.
- Do **NOT** operate cleaners beyond the Maximum Pressures listed by the manufacturer.
- All personnel involved with the operation of a cleaner system should be informed of these safety guidelines and be familiar with operations material provided by the manufacturer.
- Exercise extreme caution when working around a cleaner system operating above 50 °C (120 °F).
- Make sure all cleaners are properly mounted and secure before operation.

## Introduction

Most fiber sources contain contaminants with specific gravity or surface areas different from fiber in an aqueous slurry. These contaminants can be removed utilizing centrifugal forces. The most suitable process equipment for removing these types of contaminants is the centrifugal cleaner. Cleaners which remove contaminants with specific gravity greater than 1.0 are known as heavy, fine, or forward cleaners. Forward centrifugal cleaners work best at consistencies of less than 1%. In theory, all cleaners work best at very low consistencies where other materials (i.e., fibers) do not hinder the removal of contaminants. Larger, heavier materials (i.e., stones, tramp metal) can be effectively removed at 2% - 4% consistency using HD cleaners. Lightweight or reverse cleaners remove contaminants with a specific gravity less than 1.0 and, like the forward cleaners, operate best at consistencies less than 1%. Sand, or MD cleaners, are yet another class of cleaners that operate in the consistency range between the forward and HD cleaners, typically operate in the 1% to 2% consistency range to eliminate abrasive contaminants such as sand and grit.

Centrifugal cleaners, also known as vortex cleaners, liquid cyclones, hydrocyclones, or cyclone cleaners, are also designated by their type of rejects. For example, forward cleaners are also called heavy weight reject cleaners, heavy reject cleaners, heavy cleaners, or fine cleaners. To minimize confusion, this paper will use “forward” or “fine cleaners” as the generic name for these cleaners.

There is a range of contaminants present in pulps, even more so in recycled pulps. For many years, the paper industry has used centrifugal cleaners to remove heavy weight contaminants such as sand, glass, and metal. In the late 1960’s, it was discovered that a quantity of normal “rejects” could be increased and designated as accepts. Thus, the cleaner was reversed. This was the beginning of the reverse cleaner, designed to remove such contaminants as waxes and plastics. As a result, the standard cleaner was named the “forward” cleaner, that is, the opposite of the reverse cleaner. In the early 1980’s, a new reverse cleaner became commercially available that

reduced the volumetric reject rate while maintaining acceptable removal efficiencies. Unlike the forward and true reverse cleaner designs, both the accept and reject ports were located on the same end of the cleaner. These cleaners became known as through flow cleaners.

Simply put, reverse cleaners are a reversal of standard cleaners and are used for rejecting light weight contaminants. These cleaners are sometimes called “true reverse” cleaners. However, there are two other types of cleaners that remove light weight contaminants. These are the through-flow cleaner and the rotating body centrifugal cleaner. In the rotating body centrifugal cleaner, a motor is used to rotate the entire body of the cleaner. Typically known as lightweight rejects cleaners, light reject cleaners, or light cleaners, this paper will use the term “lightweight cleaners” to minimize confusion.

Multifunctional cleaners exist that provide both heavy and light reject removal. By performing this dual function, these cleaners can offer substantial installation benefits. These cleaners will be referred to in this paper as dual cleaners.

### Theory of operation

A cleaner essentially separates and removes undesirable components from pulp fiber by using rotational fluid motion to exploit differences in density, size, and shape between fibers and contaminants. Figure 1 shows the specific gravity of some lightweight and heavyweight contaminants. Figure 2 compares particle size to removal efficiencies of cleaners and other separation devices. As particle size falls below 60 µm, the effectiveness of cleaners is greatly reduced, regardless of the specific gravity. At particle sizes greater than 1000 µm, the selection of removal equipment, be it HD cleaners, forward cleaners, or screens, becomes more critical. Figure 3 is a simplified view of how a centrifugal cleaner removes the contaminants through a combination of centrifugal forces and drag forces. As seen in this figure, stock is pumped tangentially to the cleaner helping in the creation of a vortex. Some of the critical dimensions included in the design of a cleaner are the feed, accept, and reject nozzle diameters, the cylindrical cone diameter and length, the conical cone length and materials of construction.

### Major Forces

The first significant force exerted on the pulp slurry in a cleaner is centrifugal force. Centrifugal force is given by the equation:

$$*F_c = \frac{m * v^2}{r}$$

where

m = mass of particle, kg, (lbm)  
 r = radius of cleaner, m, (ft)  
 v = velocity of particle, m/s, (ft/s)

\*Note: To use equation in the fps system, remember to divide by the gravitational constant  $g_c = 32.174 \text{ lb-ft/s}^2\text{-lb}_f$  for numerical equality and consistency of units.

r, radius, is set by the cleaner design. That is, a smaller radius will give a higher centrifugal force. For smaller contaminants, there is a higher cleaning efficiency associated with small diameter cleaners. The optimum velocity, v, is a function of the cleaner design and the pump power which generates the required flow and associated pressure drop. For a given cleaner geometry, higher flows and therefore higher pressure drops will require more pumping energy while higher speeds may require smaller orifices in the cleaner.

Another significant force affecting cleaner performance is drag. Drag force is given by the equation:

$$*F_d = \frac{C_d * v^2 * \rho * A_p}{2}$$

where

- $C_d$  = non-dimensional particle drag coefficient  
 $v$  = particle velocity, m/s, (ft/s)  
 $\rho$  = fluid density, kg/m<sup>3</sup>, (lbm/ft<sup>3</sup>)  
 $A_p$  = particle area perpendicular to direction of flow, m<sup>2</sup>, (ft<sup>2</sup>)

\*Note: To use equation in the fps system, remember to divide by the gravitational constant  $g_c=32.174 \text{ lb-ft/s}^2\text{-lb}_f$  for numerical equality and consistency of units.

Drag force is particularly dependent on particle shape. For instance, spherical particles have minimal drag forces while plate-like particles can have the maximum drag, depending on orientation. Furthermore, drag forces will change a particle's movement depending on the size or density of a particle as well as the viscosity of the slurry. Generally, the direction of the drag force is opposite the direction of the centrifugal force. Figure 4 illustrates this relationship.

The third significant force, buoyancy, is given by the equation:

$$*F_b = \frac{V_p * \rho * v^2}{r}$$

where

- $r$  = radius of cleaner, m, (ft)  
 $V_p$  = volume of particle, m<sup>3</sup>, (ft<sup>3</sup>)  
 $v$  = particle velocity, m/s, (ft/s)  
 $\rho$  = fluid density, kg/m<sup>3</sup>, (lbm/ft<sup>3</sup>)

\*Note: To use equation in the fps system, remember to divide by the gravitational constant  $g_c=32.174 \text{ lb-ft/s}^2\text{-lb}_f$  for numerical equality and consistency of units.

These three formulae, along with the fact that contaminants in a cleaner are subjected to acceleration from a centrifugal force, suggest that contaminant motion can be modeled according to Stoke's Law of Settlement:

$$u_t = \frac{r * \omega^2 * D_p^2 * (\rho_p - \rho)}{18\mu}$$

where

- $u_t$  = terminal velocity of the particle, m/s, (ft/s)  
 $r$  = cleaner radius, m (ft)  
 $\omega$  = angular velocity, rad/s (rad/s)  
 $D_p$  = particle diameter, m (ft)  
 $\rho_p$  = particle density, kg/m<sup>3</sup> (lbm/ft<sup>3</sup>)  
 $\rho$  = fluid density, kg/m<sup>3</sup> (lbm/ft<sup>3</sup>)  
 $\mu$  = fluid viscosity, cP (lbm/ft-s)

For a given cleaner design, the greater the difference between the fluid and contaminant densities, the more likely the contaminant will be removed. Figure 4 illustrates these cleaner forces and the placement of particles with respect to the axis of rotation of the vortex and the cleaner wall. As can be seen in this illustration, the particles with the lowest specific gravity, such as plastics, will remain near the vortex while the heavier contaminants, such as sand and ink specks will be forced towards the wall of the cleaner.

## Performance characteristics

Figures 5 through 8 show typical performance curves for centrifugal cleaners. Figure 5 shows the effect of pressure drop on volumetric flow rate and is known as a cleaner capacity curve. The convention is inlet flow versus pressure drop and is unique to each cleaner design. When looking at pressure drop versus removal efficiency in Figure 6, one can find the point of optimum debris removal at the top of the curve. This curve reflects how the cleaner forces have reached their limits of applicability and retention time plays a more significant role in rejecting contaminants from the cleaner. Figure 7 demonstrates that higher reject rates do not guarantee higher reject removal efficiency. Figure 8 reiterates the point that centrifugal cleaners are usually more efficient at lower consistencies.

## Types of cleaners

### HD cleaners

The HD or High Density cleaner is placed in a system to protect downstream equipment by removing large, heavy debris. Typically, HD cleaners remove heavy rocks, glass, paper clips, staples, and tramp metal. They are used extensively in secondary fiber applications and in certain pulp mill applications.

There are two types of HD cleaners in use; the free vortex and the rotor induced. Figure 9 is an illustration of a free vortex cleaner. The free vortex cleaner is the most common HD cleaner used today. HD cleaners usually operate in the 2% to 4% consistency range and are made of stainless steel or ceramic materials.

### Fine cleaners

The primary purpose of fine/forward cleaners is to enhance end product quality and appearance. Additionally, fine cleaners will reduce abrasive wear on system components by removing high specific gravity contaminants, such as sand and grit, or near equal specific gravity contaminants, such as inks and certain plastics.

Fine cleaners can be categorized into two types; the free bleed rejects and the pressurized rejects cleaners. Free bleed means the rejects discharge to the atmosphere, usually into a trough or other reject conveyance. An advantage of the free bleed type is that plugged reject ports are easily identified. However, drawbacks to the free bleed type include potential housekeeping problems in the mill, introduction of air into the slurry, or smaller required rejects nozzles to minimize fiber loss, which increases plugging tendency.

Pressurized cleaners, on the other hand, use a control valve to provide back pressure reject control. Pressurized cleaners usually have larger reject ports, are cleaner and safer to operate, prevent the introduction of air into the slurry, and allow better process control. Plugging, though, is usually more difficult to determine in a pressurized cleaner. Figure 10 is a picture of a bank arrangement of pressurized fine cleaners.

Fine cleaners are made, for the most part, from plastic, ceramic, or stainless steel materials. They also come in a variety of head and cone designs to affect intended fluid dynamics inside the cleaners.

### Lightweight cleaners

The purpose in a system for lightweight cleaners is to increase the end product quality as well as protect paper machine wires and dryer cans. This is done by removing such contaminants as waxes, plastics, and stickies from the pulp slurry. Lightweight cleaners will also remove some of the air present in the slurry.

There are four types of lightweight cleaners. In the true reverse cleaner, a reversal of a standard cleaner is used for rejecting lightweight contaminants. Figure 11 shows a cross section of the true reverse cleaner. While most lightweight cleaners have high efficiency with a low pressure drop and reject rate, true reverse cleaners also have low air sensitivity.

Another type of lightweight cleaner is the through-flow cleaner. A through-flow cleaner, which accepts and rejects at the same end, can be further classified into two groups; free bleed and pressurized. As with the fine/forward cleaners, free bleed through-flow cleaners tend to plug more easily due to the smaller required rejects outlet while pressurized through-flow cleaners can allow plugged conditions to go unnoticed. Figure 12 is an illustration of a bank of pressurized through-flow cleaners.

A highly efficient lightweight cleaner that has low floor space requirements is the rotating body lightweight cleaner. Figure 13 shows a schematic of a rotating body cleaner, where a motor rotating the body induces the centrifugal forces necessary for separation to occur.