SIX KEY CONSIDERATIONS FOR PROPER DUST COLLECTION SYSTEM DESIGN

When it comes to industrial dust collection, it’s important to take a “system design” engineering approach versus the more common “component selection” method. This article will discuss six considerations when designing a dust collection system to help ensure a properly functioning system for your application.

Though the concept for dust collection seems simple, many things can go wrong if you don’t pay careful attention to the details. There are four key components in a dust collection system: the filter, ductwork, pickup hoods, and the air mover. Many suppliers provide excellent components that can do “their job,” but the key to a successful dust collection system is to get the components to work well together in a cohesive unit.

Dust collection basics

Figure 1 shows an example of a typical dust collection system. Dust that’s generated at a point source is pulled into pickup hoods, which is the start of the dust collection system. Airflow through the hoods can be controlled by either blast gates (common) or by duct sizing (less common but more effective). The ductwork (also called branch and trunk lines – these are closer to the dust collector) is routed through the facility, often changing directions multiple times and likely increasing in diameter along its length. The trunk (main line) of the duct terminates at the dust collector where the particles are separated from the airstream.

Ensure sufficient conveying velocity

Sufficient conveying velocity is required to pick up the dust from the pickup hoods and transport the material to the dust collector for separation from the air stream. This first consideration is fairly simple – if you can’t effectively convey the dust, then you won’t collect the dust.

The dust collector operates by either inertial or physical barrier means, for example, a cloth “sock” or fabric or sintered metal, to retain the particles while the air leaves the collector to travel to the air mover. The heart of the dust collection system is the air mover and filter combination. The symbiotic relationship between these two components is important; for instance, if the filter becomes clogged with dust, the fan (air mover) performance will likely be reduced and can cause major system problems.

In my experience, designing a proper dust collection system can be broken down into six key considerations. These six considerations are:

- Ensure sufficient conveying velocity
- Use balance-by-design for system balancing
- Install the right air mover
- Avoid plugging
- Choose an appropriate dust collector
- Consider combustible dust hazards

**FIGURE 1**

Illustration of components for a dust collection system

Though the concept for dust collection seems simple, many things can go wrong if you don’t pay careful attention to the details. There are four key components in a dust collection system: the filter, ductwork, pickup hoods, and the air mover. Many suppliers provide excellent components that can do “their job,” but the key to a successful dust collection system is to get the components to work well together in a cohesive unit.

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Particles that are sticky, have high moisture content, are heavy or oddly shaped, or are very fine can present conveying difficulties in the dust collection system. For example, wet saw dust, metal powder, fiberglass, and toner generate dusts that are known for being difficult to convey. Moving air (pneumatic conveying) is relatively inefficient at transporting bulk solids, as demonstrated by the drag force equation, which states that the drag force on a particle is proportional to the coefficient of drag, particle area, the square of the gas’s velocity, and the density of the fluid. Based on the fact that air is more than 800 times less dense than water, it becomes obvious why using air to move solids instead of water is challenging.
Most bulk solids will require significant air velocity in the ductwork to convey the material in full suspension — usually an air velocity of about 4,000 fpm (67 ft/s or about 45 mph). In some cases, it may not only be dust that is conveyed, as additional material like fumes or vapors may be included in the material stream. As shown in Table 1 from the American Conference of Governmental Industrial Hygienists (ACGIH), there are a wide range of minimum duct design velocities, which are strongly based on the material conditions.

Note that these recommendations are based on conveying velocity and not cfm, which is a common measurement among HVAC designers where only air is being transported and no consideration is made to the type of bulk solid being conveyed with the air. In some cases, velocities greater than 75 ft/s (4500 fpm or about 50 mph) are required to convey the dust-air mixture. In addition to the air velocity in the ductwork, the capture velocity at the pickup hoods is an important consideration. Again, ACGIH provides some helpful guidelines for recommended capture velocities at pickup hoods, as shown in Table 2.

Note that a range of capture velocities is provided for each condition depending upon type of dust (larger or small, sticky or not-sticky, for example) and energy (particles that include momentum when generated or not) associated with the dust dispersion, as well as situations where dust toxicity or heavy production rates may apply. For example, for wet sanding where heavy particles are released from a high-speed grinding wheel, the higher capture velocity of 2,000 fpm within the range shown in the table may be needed. Note that with high-momentum particles, you should try to orient the pickup hood to capture the particle trajectory, thereby using the stream energy to introduce the dust into the conveying duct.

Keep in mind that the maximum air velocity occurs at the open face of the pickup point in the duct, and as you move away from the duct opening farther into the duct, the velocity reduces drastically. For example, at the length of only one-half of a duct diameter away from the pickup point, the air velocity drops by 70 percent. At a full duct diameter away, it drops to only about 10 percent of the inlet velocity. This demonstrates the Dalla Valla equation, whereby doubling the distance between the dust point source and the hood inlet requires a flowrate increase of 400 percent to maintain the necessary capture velocity.

ACGIH also provides helpful guidance on the type and design of pickup hoods recommended for a myriad of applications. In most situations, a standard round duct is not suitable for adequately capturing a standard dust emission, so understanding what pickup hoods are available is essential to dust collection system design.

### Table 1

<table>
<thead>
<tr>
<th>Nature of Contaminant</th>
<th>Examples</th>
<th>Design Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vapors, gases, smoke</td>
<td>All vapors, gases, and smoke</td>
<td>Any desired velocity (economic optimum velocity usually 1000-2000 fpm)</td>
</tr>
<tr>
<td>Fumes</td>
<td>Welding</td>
<td>2000-2500</td>
</tr>
<tr>
<td>Very fine light dust</td>
<td>Cotton lint, wood flour, litho powder</td>
<td>2500-3000</td>
</tr>
<tr>
<td>Dry dusts &amp; powders</td>
<td>Fine rubber dust, Bakelite molding powder dust, jute lint, cotton dust, shavings (light), soap dust, leather shavings</td>
<td>3000-4000</td>
</tr>
<tr>
<td>Average industrial dust</td>
<td>Grinding dust, buffing lint (dry) wool jute dust (shaker waste), coffee beans, shoe dust, granite dust, silica flour, general material handling, brick cutting, clay dust, foundry (general), limestone dust, packaging and weighing asbestos dust in textile industries</td>
<td>3500-4000</td>
</tr>
<tr>
<td>Heavy dusts</td>
<td>Sawdust (heavy and wet), metal turnings, foundry tumbling barrels and shake-out, sand blast dust, wood blocks, hog waste, brass turnings, cast iron boring dust, lead dust</td>
<td>4000-4500</td>
</tr>
<tr>
<td>Heavy or moist</td>
<td>Lead dusts with small chips, moist cement dust, asbestos chunks from transite pipe cutting machines, buffing lint (sticky) quick-lime dust</td>
<td>4500 and up (~ 75 ft/s or 23 m/s)</td>
</tr>
</tbody>
</table>
static pressure loss calculations in ASHRAE, ACGIH, and Crane’s technical paper #410. Keep in mind that these calculations are based principally on airflow losses only and don’t account for particle loss effects. In other words, if your dust collection system will have a heavy particle load, using air-only calculations will significantly undersize the fan, cause pressure losses, and may result in system failure.

After determining the static pressure loss per segment, then the duct diameter, elbows, etc., are adjusted to generate equal static pressure at junctions so that the airflow is balanced. Keep in mind the minimum conveying velocity must be maintained at each segment in the dust collection ductwork.

When using the blast gate method, the duct diameters are commonly the same throughout the system and airflow is “balanced” through the manual adjustment of individual blast gates at each pickup point. A blast gate is a simple manual gate valve placed near a dust pickup hood to control the airflow into the specific branch or pickup during dust extraction. The gate can be in a closed, open, or partially open position via operator manual adjustment. Blast gates can cause systems to become unbalanced and clogged with dust or ineffective with dust capture as operator-to-operator changes to the gate can drastically affect system performance.

This method is popular as it has a long history of implementation and has been in use for operation of HVAC systems for more than 50 years. It’s important to remember that with HVAC systems there are no particulates to convey, thus, restricting the flow of air

### TABLE 2

<table>
<thead>
<tr>
<th>Condition of Dispersion of Contamination</th>
<th>Example</th>
<th>Capture Velocity, fpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Released with practically no velocity into quiet air.</td>
<td>Evaporation form tanks; degreasing, etc.</td>
<td>50-100</td>
</tr>
<tr>
<td>Released at low velocity into moderately still air.</td>
<td>Spray booths; intermittent container filling; low speed conveyor transfers; welding; plating; pickling</td>
<td>100-200</td>
</tr>
<tr>
<td>Active generation into zone of rapid air motion.</td>
<td>Spray painting in shallow booths; barrel filling; conveyor loading; crushers</td>
<td>200-500</td>
</tr>
<tr>
<td>Released at high initial velocity into zone at very rapid air motion.</td>
<td>Grinding; abrasive blasting; tumbling</td>
<td>500-2000</td>
</tr>
</tbody>
</table>

In each category above, a range of capture velocity is shown. The proper choice of values depends on several factors:

<table>
<thead>
<tr>
<th>Lower End of Range</th>
<th>Upper End of Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Room air currents minimal or favorable to capture.</td>
<td>1. Disturbing room air currents.</td>
</tr>
<tr>
<td>2. Contaminants of low toxicity or of nuisance value only.</td>
<td>2. Contaminants of high toxicity.</td>
</tr>
<tr>
<td>3. Intermittent, low production.</td>
<td>3. High production, heavy use.</td>
</tr>
<tr>
<td>4. Large hood-large air mass in motion.</td>
<td>4. Small hood-local control only.</td>
</tr>
</tbody>
</table>

### Implement balance by design

When balancing the airflow (and more importantly air velocity) in a dust collection system, there are two main approaches: the balance by design method and the blast gate method. In the balance by design method, the duct size and layout is engineered to balance the airflow in the system’s branches, pickups, and trunk based on static pressure loss through each section. If each branch has a similar static pressure loss, then the airflow, and thus velocity, through each branch will be equal. This method doesn’t use blast gates to manually adjust airflow at each branch, in contrast to the alternative balancing method.

The balance by design method is the preferred method to ensure adequate conveying velocity in each portion of the system because the method uses more information to provide a more detailed approach to system design. However, if changes are made to the layout, such as adding new branches or increasing the conveying ducting length, then the system will require reevaluation to ensure there are no negative impacts on the change. This is the one downside to using a balance by design method. Table 3 provides a comparison between the balance by design and blast gate method approaches to dust collection system design.

When using the balance by design method, the path of greatest airflow resistance is first determined through a static pressure loss calculation. This can be done through basic engineering calculations for airflow resistance through pickup hoods, ductwork branches, and trunk lines. For more information, refer to system static pressure loss calculations in ASHRAE, ACGIH, and Crane’s technical paper #410. Keep in mind that these calculations are based principally on airflow losses only and don’t account for particle loss effects. In other words, if your dust collection system will have a heavy particle load, using air-only calculations will significantly undersize the fan, cause pressure losses, and may result in system failure.

After determining the static pressure loss per segment, then the duct diameter, elbows, etc., are adjusted to generate equal static pressure at junctions so that the airflow is balanced. Keep in mind the minimum conveying velocity must be maintained at each segment in the dust collection ductwork.
Note that fans don’t typically adjust well to varied solids feedrates (especially increased solids loading), closed dampers, plugged lines, or heavy buildup in the ducts, as the fan is not a positive-displacement device that delivers a relatively constant airflow volume over a range of system pressures. As such, it’s important that you anticipate the system’s potential to experience maximum solids loading, some buildup, and other factors that may increase system resistance when selecting the fan and motor during dust collection system design.

Keep in mind that as the system resistance increases in a dust collection system, the fan won’t generate as much airflow, and, as a result, particle settlement (called saltation when in a horizontal pipe or duct section) often occurs. This will lead to not only dust buildup, but possible complete duct plugging, which renders airflow completely dead even though the fan may still be operating. Many fans will lose more than 30 percent of their airflow when the system resistance doubles, thereby allowing plugging in many cases.

A variable-speed motor isn’t necessary, though it can be beneficial in most dust collection systems. Most systems operate at a constant speed and don’t need to turn down by 25 or 50 percent during operation, as this would proportionally reduce the airflow, velocity, or both, and possibly create plugging problems.

**Avoid plugging**

Dust collection system plugging manifests itself in many forms, such as in the duct, hopper, or filter. The root causes of plugging in a system can be plentiful and include:

**Select a proper air mover**

The selection on an appropriate air mover is straightforward once the system resistance is determined. A fan or positive-displacement rotary blower are typically used to provide the suction force for the dust collection system. Air mover equipment suppliers have performance curves available, often via an online design tool, which demonstrate operating ranges for the air mover under specified conditions such as system resistance (which is the sum of the energy needed to move air and solids through the pickup hoods, branching, trunk lines, filter, and the fan), air temperature, fan blade speed, etc.
usually wasn’t originally designed to do. As a result, heavy solids loading in the line, often erratically introduced to the system, degrades system performance. If a feeder, such as a rotary airlock valve or screw feeder, can be used to modulate the solids flowrate into the duct, then this can be a simple improvement to regulate the feedrate and prevent plugging.3

Leaks. Leaks in a dust collection system can “rob the system” of conveying energy and cause material settlement and buildup. Just like a leak in your household wet-dry vac hose, the system’s dust collection performance will degrade. Leaks can occur at duct or pipeline couplings, diverters, elbows where holes have formed, blast gates, and in dust collector housings (especially at the maintenance doors). Leaks can be tested via use of talcum powder, helium tracing, or noncombustible smoke around suspected leak points.

Buildup. Figure 7 shows a significant buildup problem with resin pellets in a conveying line. The air alone moving through the system with the buildup exceeded the system resistance design condition, thereby rendering dust collection impossible as solids were introduced to the system. The buildup problem was a result of temperature-induced softening of the resin, allowing the material to fuse to the pipeline’s interior. This created increased friction and reduced the pipeline’s diameter, which both significantly increased the system’s resistance to air and solids throughput.

Buildup in the ductwork can be addressed by various methods, including: periodic manual cleaning;
“pigging,” whereby a semirigid projectile with flexible ribs and brushes is sent through the ductwork; or dry ice chips are used, where the scouring action cleans the duct and the dry ice evaporates, leaving no trace. At a minimum, the ducts should be inspected quarterly to ensure buildup isn’t affecting the system performance or leaving residual combustible dust or other solids that can allow dust explosion propagation to occur.

**Hopper design.** An often overlooked issue with dust collection system operation is the plugging of the collected material in the hopper attached to the filter-receiver. The following are possible problems that can arise when material builds up:

*Bridge*: A no-flow condition in which material forms a stable, arch-shaped obstruction over the outlet of a hopper.

*Ratholing*: A no-flow–erratic-flow condition in which material forms a stable open channel within the hopper.

If the dust or collected bulk solid is allowed to accumulate in the hopper, and if the material is cohesive (tends to stick to itself, especially when packed), then these flow problems are likely to occur. These flow problems are the result of a hopper discharging material in an undesirable flow pattern. The type of flow pattern you choose for your dust collection hopper can directly influence the type of material flow performance you’ll experience.

Unfortunately, the strong majority of standard-design collector hoppers can yield undesirable flow patterns with hard-to-handle materials since these hoppers discharge bulk materials in a funnel flow pattern. With funnel flow, some material moves while the rest remains stationary. Most dust collector conical hoppers are sloped at 60-degree angles or have a shallow pyramidal geometry that encourages stagnation in the corners (called valley angles). Though both of these hopper types are easy to build and have a relatively low cost, they generally don’t allow reliable flow with cohesive and adhesive (sticks to walls) bulk solids.

Flow problems can be prevented with hoppers specifically designed to discharge materials in a mass-flow pattern. With mass flow, all material moves whenever any is discharged. Flow is uniform and reliable due to the first-in, first-out flow sequence; ratholing is prevented; and there are no stagnant regions, so dusts and powders won’t cake. Information about how to generate mass-flow designs for hoppers can be found in Andrew Jenike’s published bulletin on the subject.

**Choose an appropriate dust collector**

The dust collector (also called an air-material separator) performance can either make or break the entire dust collection system. On one hand, a properly performing dust collector will efficiently filter the particles from the airstream, clean itself, discharge the solids into a hopper, and (if applicable) allow proper airflow through its filter media, thereby maintaining proper
conveying velocities in the system and stable fan operation. On the other hand, poor dust collector performance can allow particles to bypass through the filter, clogging and plugging, and substantially reduced airflow, rendering dust pickup and conveying ineffective.

There are many types of dust collectors, including cyclones, baghouses, and cartridge collectors. A cyclone, as shown in Figure 8a, uses inertial effects to separate the solids from the airstream, while a baghouse, shown in Figure 8b, and a cartridge collector, as shown in Figure 8c use some form of physical filter media, like cloth, synthetic fabrics, or even sintered metal to capture the dust or solids; filter media is then cleaned by various methods, with filter replacement occurring periodically. A cyclone can be highly effective for separating large particles, such as wood chips, and can be useful with separating streams with hot and abrasive bulk solids because there are no moving parts or filters to damage. However, cyclones are limited when it comes to separating fine particles; for example, using a cyclone for an air-dust mixture with a 5-micron-average particle size may not be highly practical because the particles are too light, making centrifugal forces ineffective to separate the particles from the airflow. Contrast that to a baghouse or cartridge collector with a physical filter media where collection efficiencies can approach 99.99 percent with some technologies.

When selecting a filter for your dust collector, there are many factors to consider. Here are some considerations, listed from more to less important: temperature, moisture, particle size, airstream chemistry, air-to-cloth ratio, combustibility, particle abrasiveness, and mechanical factors (for example cleaning and installation). Table 4 provides a simple summary of filter media types considering many of the previously listed factors. As you can imagine, the cost for the filters that can resist combustion, withstand high temperatures, and avoid damage from acid or alkaline attack tend to cost the most.

Baghouses and cartridge collectors must have sufficient filter area to clean the dust-laden air. An important parameter for determining the size of your dust collector is called the air-to-cloth ratio, which uses the collector’s air volume flowrate (cfm or m³/min) per filtration area (square feet or square meters). This resulting calculation is a foot-per-minute (meter-per-minute) value and is referred to as the filter’s face velocity. Note: if working with metric units, be cautious with referring to standard values reported in imperial units, as unit conversions are important.

For typical high or medium airflow reverse pulse cleaning pressure baghouse or cartridge collectors, it’s common to have an air-to-cloth ratio of 3 to 4.5 cfm per square foot (0.9 to 1.4 m³/min per square meter) for fine powders and dusts. With pleated cartridges, which have significantly more surface area, the air-to-cloth ratio is nearly halved. This generally means the dust collector unit can be smaller in size than a baghouse. Many filter suppliers will design the system based on grains per cubic foot of air (moisture), which is a parameter borrowed from HVAC design that is needed for air conditioning design and airflow movement.

Be mindful though of using a pleated cartridge filter with sticky dusts as the dust can “bridge” between the pleats, preventing effective pulse-cleaning during the unit’s cleaning cycle. Furthermore, a pleated cartridge filter generally doesn’t flex like a bag filter, thus cleaning may not be as effective with hard-to-clean dusts.

The type of filter material used will have a substantial impact on the filter’s service life and performance. In general, the interstices between the fibers that make up the filter media are considerably larger than the particles to be collected. In filters with large pores, dust penetrates the surface of the media and fills the pores, forming a filter cake on the fabric surface, a mechanism known as depth filtration. In the absence of a filter cake on its surface, the filter media is unlikely to collect fine particulate efficiently. Instead, filter media blinding will take place and over time emissions will occur when dust particles penetrate the filter.

Filter media with small pores, such as Teflon-coated, allow surface filtration, and particles are primarily collected on the bag’s surface. There’s no dust penetration into or beyond the filter media itself, preventing emission risks. Bag filters can also be purchased with oleophobic or hydrophobic coatings to minimize heavy filter cake buildup and dust adherence to the filter media.

Remember that complete filter cleaning is often not required because some dust cake on the filter improves filtration properties as the filter cake captures additional dust and can prevent dust bypass to the fan. In fact, some suppliers recommend a filter “seeding,” a filter that’s pre-coated with powder that helps to build the initial dust cake and provide a filter coating with neutral pH to avoid damage to the filter media from...
acidic or alkaline dusts.

When required, filter cleaning can be achieved through various methods including reverse airflow, shaking, and reverse high pressure pulse jets to dislodge the dust cake from the filters. With reverse airflow, a positive-displacement blower provides airflow intermittently through the inside of the filters to attempt to knock off the filter cake, whereas with a high-pressure pulse-jet cleaning system, a combination of a shock and pressure wave rapidly expands the bag filter to shake off the dust.

The cleaning cycle in a dust collector equipped with a high-pressure pulse-jet cleaning system can be set by a timer on a particular frequency or done on-demand dictated by a set differential-pressure value between the clean-air and dirty-air plenums. For example, the system can be set to initiate cleaning when it reaches a differential pressure of 3 or 4 inches water gauge. Most cleaning systems in a baghouse or cartridge collector use a dedicated solenoid at each row of filters within a dust collector's housing that delivers jet-pulsed air into each filter along the row. Cleaning of all the rows doesn’t usually occur. Instead, the rows are cleaned progressively, and the best practice is to alternate the bag or cartridge filter cleaning array to avoid blowing dirty dust onto “just cleaned” filters adjacent in the filter array.

Filters can also be cleaned online (typical) or offline, where collection isn’t actively occurring. Another important factor to consider in the filter selection and dust collector sizing process is the system’s can velocity, which is the speed of the dust-laden air as it passes upward to the level of the bag filters. If this value is beyond the supplier's recommended limits for the dust collector, then previously removed dust from the filters will be rapidly pulled back onto the filters increasing filter cake buildup and reducing airflow through the baghouse.

The interstitial can velocity is the velocity between the filters or the net cross-section of the projected filter area and can be determined by taking the dirty airflow into the filter unit and taking that value and dividing by the projected filter area (from a plan view). With many dusts, the interstitial can velocity should be less than 150 fpm, and in some limited cases, a downflow dust collector is required because the dust is too light such as in processes dealing with tissue paper dust or fumed silica.

Consider combustible dust hazards

Did you know that about 50 percent of dust explosions occur in dust collectors? Eckhoff, a well-known dust explosion expert, estimates that at least 7 out of 10 dusts can be combustible. Many dusts can burn rapidly — either in a flash fire or explosion scenario. Though most people are aware of the hazards of flammable gases and liquids, some may not know the hazards of combustible dusts in storage or dust collection equipment. A dust explosion requires five key ingredients:

- combustible dust (sugar, plastic, wood, metals, and most carbon-containing dusts)
- oxidant (oxygen is present in most process areas)
- ignition source (static discharge, hot surface, spark)
- dispersion (dust can be readily emitted from numerous sources)
- confinement (dust collector housing, silo, dryer, mill, grinding equipment)

Even if confinement is eliminated from the explosion pentagon, a dangerous flash fire deflagration event can still occur, causing major damage to property, injuries, and possibly loss of life. This last point highlights the need for a proper dust collection system because without it, dust can accumulate around the factory and on horizontal surfaces, creating ample opportunity for a hazardous flash fire event.

Excellent guidance for preventing and protecting against combustible dust hazards is available in several NFPA standards. I recommend reviewing NFPA 652: Standard on the Fundamentals of Combustible Dust and then industry and design-specific NFPA standards, including NFPA 664 (wood); NFPA 61 (food and agriculture); NFPA 484 (metals); and NFPA 68 (explosion venting). Note that NFPA standards are adopted by OSHA as consensus standards and can be mandated by an authority having jurisdiction (AHJ), such as a plant owner, insurance provider, fire chief, or building inspector.

You must not ignore protecting your dust collector from a potential combustible dust deflagration event as the collector provides the perfect conditions for a deflagration, as indicated by the five ingredients previously listed. There are many methods to protect your equipment and process through explosion containment, isolation, suppression, and venting. NFPA 69 provides excellent guidance for each of these approaches.

References

1. Industrial Ventilation, A Manual of Recommended Practice, 23rd Edition; 1998; American Conference of Governmental Industrial Hygienists (ACGIH), Cincinnati, Ohio.
6. Maynard, E., “What is a Dust Hazards Analysis (DHA) and why do I have to worry about it?” Australian Bulk Handling Review, May/June 2018.
on the fundamentals of combustible dust.

**For further reading**
Find more information on this topic in articles listed under “Dust collection and dust control” in *Powder and Bulk Engineering’s* comprehensive article index in the December 2017 issue or the Article Archive on *PBE*’s website, www.powderbulk.com (All articles listed in the archive are available for free download to registered users.)

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