EVOLUTION OF THE MECHANICAL DUST COLLECTOR IN BIOMASS APPLICATIONS

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SYNOPSIS

For more than 60 years, mechanical dust collectors have been used with biomass-fired boilers. Today, the main expectation of this equipment is to extend the operational life of the induced draft (ID) fan and pollution control equipment, located downstream in the system, by removing ash and sand particles. In some cases, the char materials are separated from the collected ash and re-injected into the boiler for improved boiler efficiency. Following a few basic guidelines on the sizing, design, and operation of this equipment will result in significant improvement in the overall system. This article discusses how the “role” of mechanical dust collectors has changed over the last six decades, as well as how equipment design and arrangement has evolved to offer the best performance for today’s boiler requirements. A checklist on how to maintain a mechanical dust collector also is included.
For more than 60 years, mechanical dust collectors have been used with biomass-fired boilers. Today, the main expectation of this equipment is to extend the operational life of the induced draft (ID) fan and pollution control equipment, located downstream in the system, by removing ash and sand particles. In some cases, the char materials are separated from the collected ash and re-injected into the boiler for improved boiler efficiency. Following a few basic guidelines on the sizing, design, and operation of this equipment will result in significant improvement in the overall system. This article will discuss how the "role" of mechanical dust collectors has changed over the last six decades, as well as how equipment design and arrangement has evolved to offer the best performance for today's boiler requirements. A Maintenance Checklist is included at the end of this article which applies to any size and type unit.

Mechanical dust collectors are simple devices with no moving parts. They are composed of a square or rectangular housing containing a number of cyclones (i.e., tube assemblies) arranged in a parallel operation. Mechanical dust collectors use both centrifugal force and gravity to remove particulate from the flue gas coming out of the boiler. Specific steps on how the internal tube assembly works are:

1. Dirty, particulate-laden gas enters the top of the inlet tube at the inlet guide vane. The vane creates a fast spiral to the gas, which produces centrifugal forces with minimal turbulence and erosion.

2. As the gas enters the inlet tube in a cyclonic pattern, the particulate is forced against the wall and pushed to the bottom. It is then expelled through an opening at the bottom of the inlet tube.

3. A vortex forms at the bottom of the inlet tube. The cleaned gas turns and makes its way through the outlet tube, into the outlet plenum, and enters the ID fan (see Figure 1).

The captured particulate gravitates to the bottom of the mechanical dust collector hopper, where it is evacuated via some type of airtight rotary or double dump valve. The particulate in biomass flue gas includes ash, char, and sand. The variation in the specific gravity (i.e., weight) and size of these components can vary greatly from application to application. Typically, char is light and coarse while ash and sand are fine and heavy.

Mechanical dust collectors work best when removing coarse, heavy particles and generally can collect 85% of particles sized 15 microns and larger.

Figure 1

How A Tube Assembly Collects Particulate

1 2 3
Obtaining an overall collection efficiency of 80 to 85% with a mechanical dust collector used on most biomass-fired boilers is very realistic, since particulate analysis shows that, on average, only 15% of the particulate is less than 10 microns in size. Efficiency also depends on the actual grain loading and specific gravity handled. Mechanical dust collectors are also highly effective in systems using coal/bagasse/sludge-fired boilers, lime/cement/carbon black kilns, and pelleting iron ore/coke equipment.

**First-Generation Mechanical Dust Collectors (STD-Limited Access)**

The first generation of mechanical dust collectors, known as the STD (standard or limited access) design, began being installed in large numbers in the early 1950s. This design is characterized by having a sloped top tube sheet, close spacing between all of the tube assemblies, and varied outlet tube lengths (see Figure 2).

The inlet opening of these mechanical dust collectors has little resistance for the front row of inlet tubes and significant resistance for the rear row. To help balance the flow, the length of each outlet tube row is different so the effect on individual pressure drop is the same. The "rear row inlet tube" resistance, however, means this design can only be effective if the tube row depth is limited. Unbalanced gas distribution and maintainability are two of the biggest problems with first generation mechanical dust collectors.

**Second-Generation Mechanical Dust Collectors (AU-Totally Accessible Unit)**

The second generation of mechanical dust collectors, known as the AU (totally accessible unit), came along several years later. It is characterized by having hoods over uniform-length outlet tubes and alleyways between groups of tubes (see Figure 3).

Although the STD design offered the smallest equipment footprint, it did not allow for inspections or part replacement without an extensive, labor-intensive rebuilding effort. The alleyways of the AU design allowed enough room for a person to move about and be able to perform any required cleaning and maintenance services. It also promoted a more balanced gas distribution (front to rear), which greatly impacts performance on collectors that are significantly deep.

As applications requiring larger boilers (and larger mechanical dust collectors) became more common, the need to access and maintain equipment internal parts became vital. Issues like inlet tube guide vane plugging, caused by gradual stratification of fly ash to cool surfaces during startup, as well as accumulated fly ash randomly falling from upper surfaces and being drawn to the nearest opening, could only be addressed with accessible equipment (see Figure 4).
Up until the early 1980s, mechanical dust collectors served as the primary air pollution control (APC) device in most biomass-fired boiler systems. As the Environmental Protection Agency (EPA) industrial emission regulations became much more rigorous, the basic design was modified in several ways to increase collection efficiency. These included:

- Using very small diameter inlet tubes (6"), relying on the theory that smaller tubes create greater centrifugal force, causing more particulate to be separated from the airstream.
- Adding "secondary shave-off," where peripheral material still in the gas going through the outlet tube is removed through a second opening in the outlet tube.
- Adding "hopper evacuation," in which 5 to 10% of the gas is taken from the upper hopper, removing the fine particles that have difficulty settling out.
- Operating two dust collectors in series.

These "upgrades" were not successful due to basic material handling issues. The 6" diameter inlet tubes plugged easily, were difficult to access, and required large numbers to handle a given air volume requirement. The secondary shave-off modification continually plugged the small openings in the outlet tubes. The hopper evacuation modification proved nearly impossible to control or regulate. Only operating two mechanical dust collectors in series provided a small increase in overall collection efficiency, ranging from 3 to 5%, yet it required twice the pressure drop and twice the plant space. Eliminating stack opacity (or stack pluming), however, was not possible as particles which cause pluming are usually less than one micron, which is extremely fine and outside the range of what mechanical dust collectors can capture.

Eventually, mechanical dust collectors were no longer used as the APC device in systems and were replaced by more sophisticated equipment, such as the fabric filter baghouse, wet and dry scrubber, and electrostatic precipitator (ESP). As mechanical dust collectors were being phased out of their APC role, the industry realized they could still help system operation by removing the larger, more destructive particles. The new role of system "pre-cleaner" was established, with the primary goal to protect the ID fan.

Without mechanical dust collector protection, either from one not being in the system, or it not working properly, damage to the ID fan can be catastrophic (see Figure 5).

Mechanical dust collectors were ideally suited for this task, as their simple, heavy construction holds up well where more sophisticated APC equipment might struggle to operate properly. Serving as a system pre-cleaner and protecting the ID fan is still the most common use of mechanical dust collectors today.

A secondary role of current mechanical dust collectors is to separate coarse char particles that have a high BTU value. Collected char can be re-injected into the boiler and may increase boiler efficiency as much as 2%. In many of today's applications, mechanical dust collectors are installed downstream of the air heater, where the number of tubes (and initial cost) can be minimized. Sometimes, however, the boiler manufacturer will install mechanical dust collectors upstream of the air heater to add further protection to boiler auxiliary equipment.
When placed upstream of the air heater, mechanical dust collectors become larger and more costly since the gas volume is greater at elevated temperatures.

**Figure 5**

**ID Fan Rotor Wear in a Biomass Boiler System Without Mechanical Dust Collector Protection**

When mechanical dust collectors first began being used in large numbers, most manufacturers offered several different inlet tube sizes. Nine and 10” size tubes, however, became the most popular and most commonly used for all biomass-fired boiler applications. The push to use these small-diameter tubes occurred when mechanical dust collectors were the system’s APC device and responsible for meeting any existing state emission regulations. Many manufacturers (and users) felt 9 and 10” tubes struck the perfect balance between air volume handling ability and collection efficiency. The small-size inlet tube was, and still is, a good selection when the air volume requirement is small and the grain loading light. The belief that 9 and 10” tube sizes would work in any situation led to them being misused in applications where medium to large size boilers required mechanical dust collectors to handle very large flue gas volumes (100,000 acfm and greater).

As the air volume requirement and number of inlet tubes required to handle that air volume increased, a phenomenon was introduced that caused mechanical dust collector performance to noticeably drop. Subsequent studies determined that the reduced performance was caused by poor gas distribution across a large area, where many tubes were operating in parallel. Regardless of how evenly the airflow was distributed across the mechanical dust collector inlet, equal airflow distribution across each tube assembly began to deteriorate. Some were overworked and others starved. The distribution phenomenon worsened as the number of inlet tubes (and especially tube depth) increased.

The best way to reduce, and possibly eliminate, the poor gas distribution phenomenon was by using larger size inlet tubes that handled more flue gas, reducing the total number required, and opening up the gas passages between all of the tubes.

Typically, a single, 9” inlet tube will handle 750 acfm, while a single 24” inlet tube will handle 5,600 acfm. This means that one 24” inlet tube can handle the airflow of more than seven 9” tubes while maintaining the same pressure drop. As a general rule, the number of tubes in a mechanical dust collector should be selected for a pressure drop between 2.50” and 4.00” w.g. This rule applies to all mechanical dust collectors, regardless of inlet tube size or casing design.

An application where the performance is 135,000 acfm at 450°F requires 183 9” inlet tubes, but only 24 tubes measuring 24”. Using the smaller number of 24” tubes eliminates any unbalanced flow performance penalty by creating an environment that helps all the inlet tubes reach their collection potential, instead of an environment where only a percentage are given that opportunity.

Laboratory testing comparing 9” and 24” tube assemblies revealed that the smaller size was slightly more efficient at collecting particles measuring less than 10 microns, but the efficiencies were very similar on particles measuring greater than 15 microns. Documented studies have established that particles less than 10 microns in size do not contribute to wear of centrifugal machinery (i.e., fans, ducts, economizers, air heaters, etc.). In the role of system pre-cleaner, the mechanical dust collector’s most important design criteria changed from that of trying to achieve maximum collection efficiency (i.e., capturing particles less than 10 microns) to that of reliably collecting larger, abrasive particles (those greater than 15 microns).
The result of this philosophy has produced the current generation of mechanical dust collector, known as the AU24” (totally accessible unit with larger tubes) design. This design, which began being used in the early 1990s, combines total accessibility (referred to earlier) and larger, 24” diameter tubes (see Figure 6).

In addition to improved performance, the current generation of mechanical dust collectors provides longer operational life. The first and second generations use smaller, thin-wall tube assembly parts where the maximum thickness is .25”. In a hostile, bark-fired boiler environment, the expected operational life of these parts is one to two years. The AU24” design uses tube assembly parts that are nearly twice as thick as earlier generations, with an expected operational life of 3 to 5 years. Staying operational saves money by reducing the number of planned outages, lowering repair costs, and having less production down time.

The AU24” design provides more reliable collector operation because of the reduced possibility of the guide vane openings becoming plugged. Tube-plugging problems are caused by the gradual accumulation of fly ash on all internal surfaces. Over time, some guide vane plugging will occur, but since the 24” diameter inlet tube has larger inlet openings, the possibility of total bridging is greatly reduced. Tube-plugging caused by the guide vane being blocked will have detrimental effects on the mechanical dust collector. A single plugged tube can reduce efficiency by as much as 25% (see Figure 7).

Another important feature of the current generation of mechanical dust collectors is the design of the bottom half of the inlet tubes located in the upper hopper area. Some manufacturers use the peripheral removal concept (i.e., flat boot discharge), where the collected material discharges horizontally from slots at the base of the inlet tubes (see Figure 8).

The same illustration shows the conical removal concept, which is the preferred method of discharging the particles from the inlet tubes. The upper hopper area is a critical zone, since this is where particles are drawn to the lower hopper area for eventual removal, and preventing re-entrainment is extremely important. The upper hopper area must contain only stagnant gases, with no internal movement to stir up the collected particles and prevent them from settling to the bottom hopper area. The peripheral discharge design promotes disruptive air currents, making it much more difficult to evacuate material that has already been collected. With all other factors being equal, the conical removal concept adds approximately 5% to overall dust collector efficiency versus the peripheral removal concept.
A final feature of the AU24 design is the use of outlet hood turning vanes. Two-thirds of the total pressure drop across a mechanical dust collector is created as the cleaned gases make their way through the outlet tubes. The gases going through the outlet tubes have extremely high spiraling velocities that, left unguided, make a hard, perpendicular impact against the casing hood roof. This impact creates airflow turbulence and adds to the total system pressure drop.

Strategically placed outlet hood turning vanes direct the gases toward the outlet duct with minimal resistance. In addition, they help balance the pressure drop across the mechanical dust collector (front to rear). This ensures each section is working equally, preventing re-entrainment of tube assemblies being overloaded and plugging of the hopper (see Figure 9).

The role and design of mechanical dust collectors has changed a great deal over the past half century, yet they are still a vital and low-cost contributor in biomass-fired boiler systems. Taking advantage of the latest developments described in this article concerning equipment sizing, selection, and maintenance will greatly contribute to successful system operation and extended equipment life.


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**Monitor the Pressure Drop**
- Use instrumentation to confirm the pressure drop across the unit (inlet flange to outlet flange) is near the original design conditions.
  
  *(Note: Mechanical dust collectors operate at optimum efficiency when sized for a pressure drop between 2.50” and 4.00” w.g. A sharp increase in the pressure drop usually indicates internal plugging has occurred and the unit is no longer working properly.)*

**Hopper Evacuation**
- Check for plugging.
- Check for air-in leakage via hopper access doors, hopper flanges and airlock devices.
  
  *(Note: One of the most critical aspects to successful mechanical dust collector operation is making sure the hoppers are properly and continually evacuated. If a single hopper plugs (on a multiple hopper application), the unit’s efficiency can be reduced by as much as 50 to 75%. Air-in leakage is the primary cause of hopper plugging.) Hopper plugging is the single most common item that affects mechanical dust collector performance.*

**ANNUAL / YEARLY BASIS**

**Casing Inspection and Cleaning**
Evaluate the condition of all tube assembly parts for possible replacement.

- Guide vanes (the most common wear item)
- Inlet/outlet tubes
  - Check for plugging.
  - Tubes with holes must be replaced.
- Tube sheets/casing
  - Holes must be patched.
  - Dirty and clean compartments must be kept airtight and separate.
- Make notes on any material buildup in a particular area or unusual wear patterns.

**Hopper Inspection and Cleaning**
- Fire – Check for evidence of fire.
- Clinker buildup - Verify no buildup has occurred.
- Sidewalls
  - Holes must be patched.
  - Cracks in the welds must be repaired.
- Access door
  - Seal gasket must be replaced every time the access door is opened.
- Poke-hole
  - Must be capped off and sealed while the unit is being operated.

**Inspection/Rebuild of the Hopper Rotary Feeders/Double Dump Valves**
(includes internal and external components)
- Access panel
  - Seal gasket material must be replaced every time the access panel is opened.
- Airlock devices (typical biomass-fired boiler applications)
  - Recommended to be rebuilt every two years.