COLLECTION EFFICIENCY EVALUATION OF BAFFLE-TYPE PRE-SEPARATOR CONFIGURATIONS: EFFECTS OF BAFFLE LOCATION AND INLET VELOCITIES


ABSTRACT. Some cotton gins across the Cotton Belt use an abatement system consisting of a baffle-type pre-separator followed by cyclones to control the emissions from the cotton gin’s various exhausts. Very limited information exists in the literature which discusses the effects of baffle location and critical velocity on the pre-separator’s collection efficiency. In this study, a range of critical air velocities and loading rates were evaluated to determine the effect of baffle location of the pre-separator’s collection efficiency when using cotton gin waste. None of the treatments significantly affected the over-sized cyclone or over-all collection efficiency. The pre-separator collection efficiency was higher (81%) when the baffle placed at one-third the overall width of the pre-separator from the inlet than when placed at one-half (78%) or two-thirds (75%). The pre-separator collection efficiency was 79.4% at 18.3 m s⁻¹ (3600-fpm) inlet velocity which was significantly higher than 78.2% at 20.3 m s⁻¹ (4000 fpm) and 78.5% at 22.4 m s⁻¹ (4400 fpm). Loading rate did significantly affect the pre-separator efficiency, but not to the extent of inlet velocity. The sieve analysis indicated that the pre-separator removed the majority of material larger than 180 µm; however, the pre-separator did allow a substantial amount of lint to pass through to the cyclone. The baffle-type pre-separator performed well in reducing the course material loading rate entering the cyclone.

Keywords. Cotton gin, Cyclone, Particulate matter, 1D-3D, Emissions, Pre-separator, Trash, Waste.

The most common abatement devices used on cotton gin exhausts are cyclones. These devices are typically used as a single stage control technology and are therefore used to remove the larger gin waste (e.g., sticks, burrs, lint, and leaf trash) and fine dust (particulate matter less than 100 µm in diameter). Early cyclones used in the cotton ginning industry were large-diameter, low-velocity devices designed primarily for the collection of large trash. During the 1960s, the high-efficiency, small-diameter cyclone, commonly referred to as the 2D-2D design, was developed for the cotton ginning industry in an effort to reduce particulate matter (PM) emissions (Harrell and Moore, 1962; Baker and Stedronsky, 1967). In the late 1970’s, Parnell and Davis (1979) introduced the 1D-3D cyclone design which was reported to have a higher fine dust collection efficiency than the 2D-2D cyclone design. Studies have shown that single conventional cyclones, similar to the 2D-2D design, could remove 10-µm particles with 85% to 90% efficiency, 5-µm particles with 75% to 85% efficiency, and 2.5-µm particles with 60% to 75% efficiency (EC/R Incorporated, 1998) and could collect particles larger than 20 µm with 100% efficiency (Avant et al., 1976). The 2D2D and 1D-3D cyclones were designed as fine dust collectors; however as previously stated, most cotton gins use these abatement devices to remove both the larger gin waste and the fine dust.

According to Baker et al. (1995), secondary abatement technologies such as baffle-type pre-separators have been incorporated into some cotton gin abatement systems in order to overcome problems encountered with using cyclones to remove both the large cotton gin waste and the fine dust. These problems have included: choking in the transition, narrow inlet of the original 1D-3D cyclone design, and trash outlet; cyclone wear due to the presence of sand and other abrasives found in the gin waste; and fluctuations in airflow rates entering the cyclones due to changes or modifications to the processing system prior to the cyclones, which tend to decreased cyclone efficiencies. The typical pre-separator used in the cotton ginning industry receives the material laden air from all or the majority of the cotton gin process streams and removes the large gin waste, thus reducing the loading rates, choking tendency, and wear while balancing the airflow rates to the cyclones that follow the pre-separator. Although these devices have been used at commercial cotton gins in Texas, California, and Australia since the mid-1970s (Baker et al., 1995), there is very little information in the
literature discussing the design and collection efficiencies of the baffle-type pre-separator prior to the mid-1990s.

Mihalski et al. (1993) and Mihalski (1995) reported on studies conducted using a small-scale baffle-type pre-separator designed for a single 10.2-cm (4-in.) diameter 1D-3D or 2D-2D cyclone. The test material, cotton gin waste with the fine dust removed and replaced with corn dust, provided known quantities of both the gin waste and fine dust to be introduced into the system. The results indicated that using a pre-separator prior to a 2D-2D cyclone significantly reduced the emission concentrations in 11 out of 12 comparison tests and using a pre-separator prior to a 1D-3D cyclone significantly reduced the emission concentrations in only four of nine comparison tests (Mihalski et al., 1993). The optimum pre-separator design included placing the baffle in the center of the separator and operating at 5.1- to 6.1-m s⁻¹ (1000- to 1200-fpm) critical velocity (Mihalski, 1995). Using the optimum design in series with a 1D-3D cyclone reduced emission concentrations from 170 to 16 mg m⁻³ when compared to using only a 1D-3D cyclone to remove both ground cotton gin waste and fine dust at an inlet loading rate of 90 g m⁻³. Similarly, utilizing the optimum baffle-type pre-separator design in series with a 2D-2D cyclone reduced emission concentrations from 200 to 28 mg m⁻³ when compared to using only a 2D-2D cyclone.

Columbus (1994) reported on using a 76.2-cm (30-in.) wide baffle-type pre-separator, with the baffle located at 25.4-cm (10-in.) from the inlet and operated at a critical velocity of 4.6 m s⁻¹ (900 fpm), in series with a 61.0-cm (24-in.) 1D-3D and in series with a 66.0-cm (26-in.) 2D-2D cyclone to collect cotton gin waste from picker harvested cotton. Results of the study indicated that the pre-separator reduced the total emissions by 15% to 17%. Baker et al. (1995) used a 76.2-cm (30-in.) wide baffle-type pre-separator, with the baffle located at 25.4-cm (10-in.) from the inlet and varied the critical velocity. The pre-separator was about 80% to 90% efficient in removing stripper harvested cotton gin waste prior to a cyclone, and the pre-separator collection efficiency tended to increase as the critical velocity decreased to about 8.1 m s⁻¹ (1600 fpm).

Results from these tests indicated that using a pre-separator in series with a 1D-3D cyclone increased the cyclone emissions when compared to using only a 1D-3D cyclone, but this result was attributed to lint re-circulation near the cyclone’s trash exit. The pre-separator in series with a 2D-2D cyclone tended to reduce emissions by about 8% when compared to using only a 2D-2D cyclone.

A more recent study conducted by Wang et al. (2004) used 10.2-cm (4-in.) 1D-3D and 1D-2D cyclones and a baffle-type pre-separator with the baffle located in the center of the separator. This study was conducted using tub-ground West Texas stripper-harvested cotton gin waste. Results from the study showed that the overall collection efficiency for both systems exceeded 97% and there were no significant differences between the emission concentrations for the pre-separator/1D-3D system and pre-separator/1D-2D system.

In the current literature, only two studies have evaluated baffle-type pre-separators in terms of baffle location in terms of the distance from the inlet to the baffle and these two studies were conducted on small scale pre-separators where the cotton gin waste was modified from its original state to prevent system choking. The purpose of this study was to evaluate a 76.2-cm (30-in.) wide baffle-type pre-separator in terms of the separator’s collection efficiency, the collection efficiency of the over-sized cyclone that followed the pre-separator, and the overall collection efficiency with different inlet air velocities, gin waste loading rates, and baffle locations.

MATERIALS AND METHODS

The test system included: a variable speed conveyor to regulate the amount of material entering the system (fig. 1); a variable speed fan to convey the material through the system; a baffle-type pre-separator (fig. 2); and an over-sized cyclone. The 38.1-cm (15-in.) wide and 228.6-cm (90-in.) long conveyor belt was equipped with 22.9-cm (9-in.) side rails so that a known volume of material could be placed on the belt prior to each test. The fan was capable of moving 0.83 m³ s⁻¹ (1750 cfm) of air through the entire system. The length of the baffle-type pre-separator, from the inlet to the outlet, was 76.2 cm (30 in.), and the width, from side to side, was 48.3 cm (19 in.). The 3.2-mm (1/8-in.) thick baffle plate spanned the width of the pre-separator and extended 55.9 cm (22 in.) into the main body of the pre-separator from the top of the pre-separator. The baffle plate could be positioned at different points between the inlet and outlet. The main body of the pre-separator was 96.5 cm (38 in.) tall with a 106.7-cm (42-in.) tall transition down to a 20.3-cm (8-in.) dropper. A hopper was attached to the bottom of the dropper to collect the material removed from the air stream by the baffle-type pre-separator. The diameter of the piping entering and exiting the pre-separator was 20.3 cm (8 in.). One side of the pre-separator was covered with Lexan so the material flow patterns could be observed during the tests. The over-sized cyclone that followed the pre-separator was an 86.4-cm (34-in.) diameter 1D-3D cyclone with a 2D-2D inlet and a D/3 trash outlet (Armijo et al., 1992). The cyclone’s trash exit was equipped with a 208.2-L (55-gal) hopper to collect all the material the cyclone removed from the air stream.

Figure 1. Material feeding system.
The average bulk density of the gin waste was 160.2 kg m$^{-3}$, based on 10 random samples collected from the tub-ground West Texas stripper-harvested cotton gin waste.

Prior to each run, velocity and static pressure readings were made to ensure that the airflow rates were properly set. Barometric pressure, relative humidity, and ambient temperature readings were collected prior to each run and were used to calculate air density. If significant differences were detected in the air density values, then the airflow rate was adjusted by adjusting the current supplied to the fan motor to account for the variation in air density. The parameters measured during and after the run included run time, mass of material captured by the baffle-type pre-separator, and mass of material captured by the over-sized cyclone. Once a run was completed, sub-samples of the material captured by the baffle-type pre-separator and the over-sized cyclone were set aside for sieve analysis.

The baffle-type pre-separator collection efficiency was calculated as the mass of material collected by the pre-separator divided by the mass of material introduced into the system [27.7 kg (50 lb)]. The over-sized cyclone collection efficiency was calculated as the mass of material collected by the cyclone divided by the mass of material introduced into the system minus the mass of material collected by the pre-separator. The overall collection efficiency was calculated as the sum of the mass of material collected by the pre-separator and the cyclone divided by the mass of material introduced into the system.

A sieve analysis was performed on the samples collected from the pre-separator and the cyclones to determine the size distribution of the material. A 50-g sub-sample was placed in the top sieve of a stack and shaken for 20 min in a Roto-Tap (W.S. Tyler, Mentor, Ohio) shaker. The following sizes of sieves were used: 16.0 mm (5/8 in.), 9.5 mm (3/8 in.), 8.0 mm (5/16 in.), 4.75 mm (#4), 2.0 mm (#10), 1.4 mm (#14), 710 µm (#25), 180 µm (#80), 75 µm (#200), and pan.

**RESULTS AND DISCUSSION**

The pre-separator, over-sized cyclone, and overall collection efficiencies are reported in table 1. Pre-separator collection efficiency was significantly impacted by inlet air velocity and loading rate; however, there were no effects due to the interaction of inlet air velocity and loading rate. Baffle-type pre-separator collection efficiency was significantly higher at lower inlet air velocities [22.4 to 18.3 m s$^{-1}$ (4400 to 3600 fpm)], ranging from 76.5% to 79.4%. Pre-separator efficiency for the lowest gin waste loading rate of 1.1 kg min$^{-1}$ (2.4 lb min$^{-1}$) was 77.6% and was significantly lower than the overall system efficiency.
Table 1. Pre-separator, cyclone, and overall collection efficiencies\[a\] for the baffle-type pre-separator study.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pre-separator Inlet Velocity, m s(^{-1}) (fpm)</th>
<th>Cyclone Efficiency</th>
<th>Overall Efficiency</th>
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<tbody>
<tr>
<td></td>
<td>18.3 (3600)</td>
<td>79.4 a</td>
<td>78.6 a</td>
</tr>
<tr>
<td></td>
<td>20.3 (4000)</td>
<td>78.2 b</td>
<td>79.0 a</td>
</tr>
<tr>
<td></td>
<td>22.4 (4400)</td>
<td>76.5 c</td>
<td>78.9 a</td>
</tr>
<tr>
<td>Loading Rate, kg min(^{-1}) (lb min(^{-1}))</td>
<td>1.1 (2.4)</td>
<td>77.6 b</td>
<td>78.4 a</td>
</tr>
<tr>
<td></td>
<td>1.8 (4.0)</td>
<td>78.1 a</td>
<td>78.8 a</td>
</tr>
<tr>
<td></td>
<td>2.6 (5.7)</td>
<td>78.4 a</td>
<td>79.4 a</td>
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</table>

ANOVA - P value

<table>
<thead>
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<th>Source of variation</th>
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<th>Cyclone</th>
<th>Overall</th>
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<td>Inlet velocity</td>
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<td>Loading rate</td>
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<td>0.19</td>
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<td>Inlet velocity × loading rate</td>
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<tr>
<td>Model</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

\[a\] Means in the same column for a treatment followed by the same letter are not significantly different as determined by Ryan-Einot-Gabriel-Welch test based on range, REGWQ, (P ≤ 0.05).

When comparing pre-separator collection efficiencies among critical velocities (fig. 5), it appeared that efficiency may increase with increasing critical velocity. After further study, it was found that the increase was actually due to decreased distance of the baffle from the inlet. Also, for a particular baffle location, the pre-separator efficiency decreased with critical velocity. Based on the data shown in figure 5, it appeared that the airflow rate, and thus critical velocity, would have to have been substantially decreased when the baffle was located further from the inlet [i.e. 53.3 cm (21 in.) from the inlet] in order to obtain similar collection efficiencies as those found when the baffle was located closer to the inlet [i.e. 22.9 cm (9 in.) from the inlet].

Figure 6 shows the over-sized cyclone collection efficiency as a function of pre-separator inlet air velocity and cyclone inlet velocity for the three baffle locations. It appears that the over-sized cyclone collection efficiency was highest when the baffle was located 53.3 cm (21 in.) from the inlet. However, when the baffle was located 53.3 cm (21 in.) from the inlet, the baffle-type pre-separator collection efficiency was the lowest allowing more material to enter the cyclone. The cyclone inlet velocities ranged from 7.2 to 8.8 m s\(^{-1}\) (1414 to 1728 fpm), which were well below the recommended inlet velocity of 3200 fpm for 1D-3D cyclones. Reducing the inlet velocity from 8.8 to 7.2 m s\(^{-1}\) (1728 to 1414 fpm) had little effect on the cyclones collection efficiency.

There were no significant differences in overall (pre-separator followed by a 1D-3D cyclone) collection efficiencies due to pre-separator inlet velocity or loading rate (table 1). The baffle location also had little effect on the overall collection efficiency (fig. 7), although, the average overall collection efficiency appeared to be slightly higher when the baffle was located 53.3 cm (21 in.) from the inlet than when the baffle was located 22.9 or 38.1 cm (9 or 15 in.) from the inlet. In general, the pre-separator removed about 80% of the material entering the abatement system (fig. 8). Based on visual inspection, the material removed by the pre-separator looked very similar to the material being fed through the

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Figure 3. Pre-separator collection efficiencies at pre-separator inlet air velocities. Error bars represent two-sided 95% confidence limits for the means.
system, while the material removed by the over-sized cyclone appeared to consist mainly of lint and fine dust (fig. 9). Photographs of the sieved material: 16.0-mm (5/8 in.), 8.0-mm (5/16 in.), 2.0-mm (#10), 710-µm (#25), 75-µm (#200), and smaller captured by the pre-separator are shown in figure 10. There were no significant differences in the percentages of material captured by the pre-separator collected on any of the sieves among pre-separator inlet air velocities, and only the percentage collected on the 2.0-mm (#10) sieve was significantly different (P-value = 0.02) among gin waste loading rates. Analysis of variance results showed that material captured by the pre-separator had significantly higher levels of material collected on the 2.0-mm (#10) sieve at the lowest gin waste loading rate (30.2%) than at the highest loading rate (28.6%). The reason for this difference occurring for only the 2.0-mm (#10) sieve was not apparent.

More significant differences were detected for the sieve analysis of the samples captured by the over-sized cyclones

Figure 4. Pre-separator collection efficiencies at gin waste loading rates. Error bars represent two-sided 95% confidence limits for the means.

Figure 5. Pre-separator collection efficiency at pre-separator critical velocities. Error bars represent two-sided 95% confidence limits for the means.
than by the pre-separator. The material captured by the cyclone at the lowest gin waste loading rate (0.3%) had a significantly (Pvalue = 0.002) lower percentage of material collected on the 4.75-mm (#4) sieve than the medium and highest loading rates (0.4 %). The 2.0-mm (#10), 1.4-mm (#14), and 710-µm (#25) sieves, and the < 75-µm pan showed significant differences in collected material among pre-separator inlet air velocities (table 2). For all three sieves, the lower inlet velocity resulted in significantly lower percentage of material captured by the cyclone collected on the sieves; 2.1%, 3.4%, and 8.6% for the 2.0-mm (#10), 1.4-mm (#14), and 710-µm (#25) sieves, respectively. On the other hand, there was a significantly larger percentage of the material captured by the cyclone collected on the < 75-µm pan for the lower pre-separator inlet air velocity (18.4%) than for the highest velocity (16.7%).

Figures 11 and 12 show the percentage of material collected on each sieve, based on the total amount of material captured by the pre-separator and cyclone combined, for the pre-separator and cyclone, respectively. There appeared to be very little difference in the sieved material captured by the pre-separator, due to baffle location, except for the 16.0-mm (5/8-in.) sieve, where the percentage of material decreased as the baffle was moved away from the inlet (fig. 11). For
material captured by the cyclone (fig. 12), the percentage of material on the 4.75-mm (#4), 2.0-mm (#10), 1.4-mm (#14), 710-µm (#25), 180-µm (#80), and 75-µm (#200) sieves increased as the baffle was moved away from the inlet. It would be expected that if a trend in the amount of material collected by the pre-separator for a particular sieve with changing baffle distance from the inlet was revealed, then the opposite trend in the amount of material collected by the cyclone for that sieve would follow, especially for larger material. Inexplicably, this was not seen in the analyses. Consistent with expectations of pre-separator and cyclone performance, a comparison of figures 11 and 12 revealed that the pre-separator removed the majority of the material ranging from 180 µm #80 to 16.0-mm (3/8-in.) sieve, while the cyclone captured the majority of the material smaller than 180 µm. One observation of note is that a large fraction of lint passed through the pre-separator to the cyclone, which may have influenced performance.

**CONCLUSION**

A study was conducted to evaluate the effects of pre-separator inlet air velocity, gin waste loading rate, and baffle location on the collection efficiency of a baffle-type pre-separator followed by an over-sized 1D-3D cyclone. Results from the study indicated that the baffle-type pre-separator’s collection efficiency ranged from 76.5% to 79.4% over the range of inlet air velocities [18.3 to 22.4 m s⁻¹ (3600 to 4400 fpm)] and was impacted to a greater extent by inlet

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**Figure 8.** Material captured by the pre-separator and by the cyclone, and the material escaping capture at pre-separator critical velocities.

**Figure 9.** Material captured by the baffle-type pre-separator and by the cyclone.

**Figure 10.** Material captured by the baffle-type pre-separator segregated by sieve size.

**Table 2.** Results from sieve analysis with significant differences among pre-separator inlet air velocity for material captured by the over-sized cyclone.

<table>
<thead>
<tr>
<th>Inlet Velocity m s⁻¹ (fpm)</th>
<th>Percentage Material per Sieve Size[^a]</th>
<th>Pvalue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.0 mm (#10)</td>
<td>1.4 mm (#14)</td>
</tr>
<tr>
<td>18.3 (3600)</td>
<td>2.1 c</td>
<td>3.4 b</td>
</tr>
<tr>
<td>20.3 (4000)</td>
<td>2.5 b</td>
<td>3.9 a</td>
</tr>
<tr>
<td>22.4 (4400)</td>
<td>2.8 a</td>
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</table>

[^a]: Means in the same column followed by the same letter are not significantly different as determined by Ryan-Einot-Gabriel-Welch test based on range, REGWQ, (P ≤ 0.05).
velocity than loading rate. The pre-separator’s collection efficiency increased as the baffle was moved closer to the inlet and decreased as the airflow rate was increased at a given baffle location. The collection efficiency of the over-sized cyclone and over-all collection efficiency of the pre-separator followed by the cyclone were 78.8% and 95.4%, respectively. There were no differences in either the cyclone collection efficiency or over-all efficiency for any of the treatments. Based on the sieve analysis, the pre-separator removed the majority of the material larger than 180 µm (#80 sieve), while the cyclone captured the majority of the finer material. The pre-separator did allow a large portion of lint to pass through to the cyclone. The baffle-type pre-separator performed well at reducing the coarse material loading rate entering the cyclone.

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REFERENCES


