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Study of "Baffle Type Pre-separator Plus Cyclone" Abatement Systems for Cotton Gins

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Abstract. *"Pre-separator plus1D2D cyclone" and "pre-separator plus 1D3D cyclone" systems were tested with ground gin trash, which contains 10.35% lint fiber and 5.49% fine dust (less than 100 μm). Test results indicate that the pre-separator collected gin trash at over 97% collection efficiency. There were no significant differences in emission concentrations and overall collection efficiencies from these two systems, even though the 1D3D cyclone collection efficiencies were slightly higher than 1D2D cyclone when tested with high lint content trash and with pre-separator in the system. "Pre-separator plus 1D2D cyclone" system could perform as efficiently as a "pre-separator plus 1D3D cyclone" system when tested with high lint content gin trash.*

Keywords. Pre-separator, cyclone, 1D2D, 1D3D, cotton gin, gin trash, particulate matter, efficiency

Introduction

Cyclones, because of their simplicity and low-cost, have been used as both large gin trash and fine particulate matter (PM) collectors in the cotton gin industry for decades. The most commonly used cyclone designs in ginning industry are the 2D2D cyclone (Shepherd and Lapple, 1939) and 1D3D cyclone (Parnell and Davis, 1979). It has been reported that the 1D3D is more efficient than the 2D2D for fine dust collection. As a consequence, a number of states have classified the 1D3D as Best Available Control Technology (BACT) and in many cases require that all emitting points of a gin utilize the 1D3D for the abatement system. However, a cyclone's performance characteristics are highly dependent upon the characteristics of the PM in the inlet air stream. Mihalski et al (1993) and Hughs and Baker (1996) reported "cycling lint" near the trash exit for the 1D3D and 2D2D cyclone designs when the PM in the inlet air stream contained lint fiber. Mihalski reported a significant increase in the exit PM concentration for these high efficiency cyclone designs and attributed this to small balls of lint fiber "cycling" near the trash exit causing the fine PM that would normally be collected to be diverted to the clean air exit stream.

It was hypothesized that a cyclone design with a larger exit point for the collected PM and trash with fewer turns would solve the cycling lint problem. The 1D2D (Kaspar and Parnell, 1994 and Simpson, 1996) and barrel cyclone (Tullis et al, 1997) designs were developed. Tulles et al (1997) and Flannigan et al (1997) reported significantly lower PM concentrations emitted by the barrel and 1D2D cyclone designs compared to the 1D3D and 2D2D cyclone designs when the inlet air stream contained the same concentrations of cotton gin trash/fine dust and the gin trash contained a relative high fraction of lint fiber (high lint gin trash/fine dust). These results suggested that a simpler, low-pressure drop cyclone design (1D2D or barrel) would result in a lower emission rate of PM for all exhausts containing a significant fraction of lint fiber. The findings from these studies were that the 1D2D or barrel cyclone designs performed better when the inlet air stream contained significant lint fiber. These cyclones did not perform as well as 1D3D or 2D2D cyclone designs for inlet air streams with fine dust only! Hence, they are not "more efficient".

Milhaski et al. (1994) and Baker, et al. (1995) attempted to address the performance of "high efficiency" cyclones by removing gin trash (and lint) prior to cyclone collection with intention of increasing 1D3D and 2D2D cyclone performance levels to the same levels resulting from collection of fine dust only. The baffle type pre-separator was used in these studies as a pre-separation device to remove large gin trash. These research results indicated that the pre-separators had very positive impact on cyclone collection performance. However, all these studies on "pre-separator plus cyclone systems" were focused on 1D3D and 2D2D cyclone designs. No such research has been done with a pre-separator plus 1D2D cyclone system. The purpose of this research was to obtain additional information on "the pre-separator plus cyclone" systems to collect gin trash/dust with high lint fiber content.

Method and Materials

A testing system (figure1) similar to the one developed by Milhaski et al. (1994) was used for this research. This system was a pull system. The blowers pulled the air along with the gin trash from the feeding mechanism directly into the conveying pipe to the pre-separator. The large trash was collected by the pre-separator with fine dust passing through to the cyclone. Collection hoppers were connected to the bottoms of pre-separator and cyclone dust outlets, respectively. The cleaned air flowed out of cyclone through the outlet-conveying pipe to a filter holder. The filter captured all PM emitted from the cyclone. The clean air passing through the filter flowed through an orifice meter to the blowers and was discharged into the testing room. The orifice meter used in the system was used to maintain a designed airflow rate by monitoring the pressure drop across the orifice meter during the test. The relationship between flow rate and pressure drop across the orifice meter is shown in the equation 1 and the equipment used in the testing system is listed in the table 1.

$$Q = 3.478 * K * D_o^2 * \sqrt{\frac{\Delta P}{\rho_a}} \quad \text{……………….........…………} (1)$$

where

Q = air flow rate through orifice meter (m^3/s),
K = orifice meter coefficient (dimensionless),
D_o = orifice diameter (m),
ΔP = pressure drop across orifice meter (mm H_2O), and
ρ_a = air density (kg/m^3).

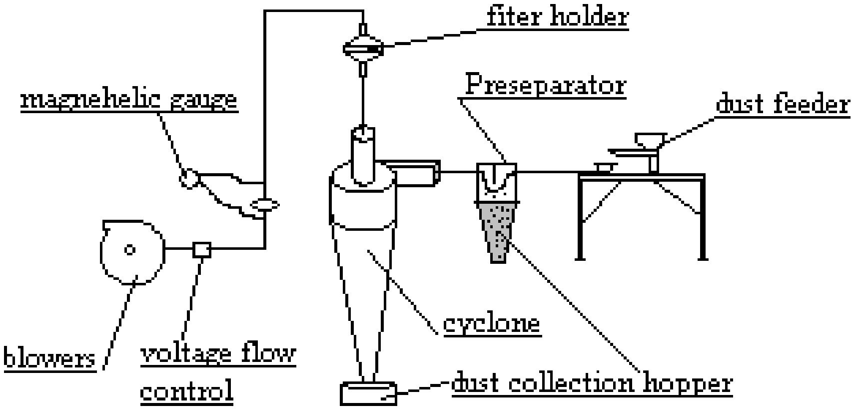

Figure 1. Schematic of the testing system

Table1. Equipment used for the testing system

Equipment	Model	Parameters
Cadillac hand-held blowers	HP-33	1.42 m^3/ min, 2989 Pascals (50 cfm, 12 in. w.g.)
Orifice meter	Made in house	Calibrated with Meriam Laminar Flow Element with accuracy: ± 0.7% reading, range: 0-3.11m^3/min
Dwyer Instruments, Inc. magnahelic differential pressure gages	---	Range: 0 – 1245 Pascals (0-5 inch w.g.), accuracy: ± 24.9 Pascals (0.1 inch w.g)
Syntron magnetic dust feeder	F-TO	---
Filter holder	Made in house	20.3 cm x 25.4 cm (8 in. x 10 inch)

For each test, testing time was 3 minutes. The system was cleaned between tests. The filters weighed with a microbalance (range: 0-101mg, accuracy: ±0.1mg) before and after testing to determine total penetrating weights. The feeding rates, emission concentrations and collection efficiencies were determined with the following equations:

$$F = L * Q \quad \text{……………….....…………………………….. } (2)$$

where

F = feeding rate (g/s),
L = total inlet loading rate (g/m^3), and
Q = system airflow rate (m^3/s).

$$EC = \frac{FW_2 - FW_1}{Q * T} * 1000 \quad \text{……….....…………………….. (3)}$$

where

EC = emission concentration (mg/m^3),
FW_1 = pre-weight of filter (g),
FW_2 = post-weight of filter (g),
Q = system air flow rate (m^3/s.), and
T = testing time for each sample (s).

$$EF_p = \frac{CW_P}{TF} * 100 \quad \text{……………………………................. (4)}$$

where

EF_p = Pre-separator collection efficiency (%),
TF = Total inlet feeding (g), and
CW_p = Collected by pre-separator (g),

$$EF_c = \frac{(TF - CW_p) - (FW_2 - FW_1)}{(TF - CW_p)} * 100 \quad \text{…………...……(5)}$$

where

EF_c = cyclone collection efficiency (%),
TF = Total inlet feeding (g),
CW_p = Collected by pre-separator (g),
FW_1 = pre-weight of filter (g), and
FW_2 = post-weight of filter (g),

$$EF_o = \frac{TF - (FW_2 - FW_1)}{TF} * 100 \quad \text{……………....................(6)}$$

where

EF_o = overall collection efficiency (%),
TF = Total inlet feeding (g),
FW_1 = pre-weight of filter (g), and
FW_2 = post-weight of filter (g),

The airflow rates of the testing system were determined by using Texas A&M cyclone design velocity (Parnell, 1996). Table 2 shows the airflow rate and cyclone inlet velocity.

Table 2. Airflow rates of the testing systems

	Diameter of cyclone	Design velocity	Airflow rate of system
1D3D system	10.16 cm (4 inch)	16 m/s (3200 ft/min)	0.021 m^3/s (44.4ft^3/ min)
1D2D system	10.16 cm (4 inch)	12 m/s (2400 ft/min)	0.016 m^3/s (33.3 ft^3/ min)

Pre-separator

The pre-separator used in this research was initially designed and constructed for Milhaski 's research in. 1994. He tested a number of different designs. His findings were that the pre-separator with the baffle plate in the center of the chamber yielded the best performance. Figure 2 shows the design and dimensions of this pre-separator.

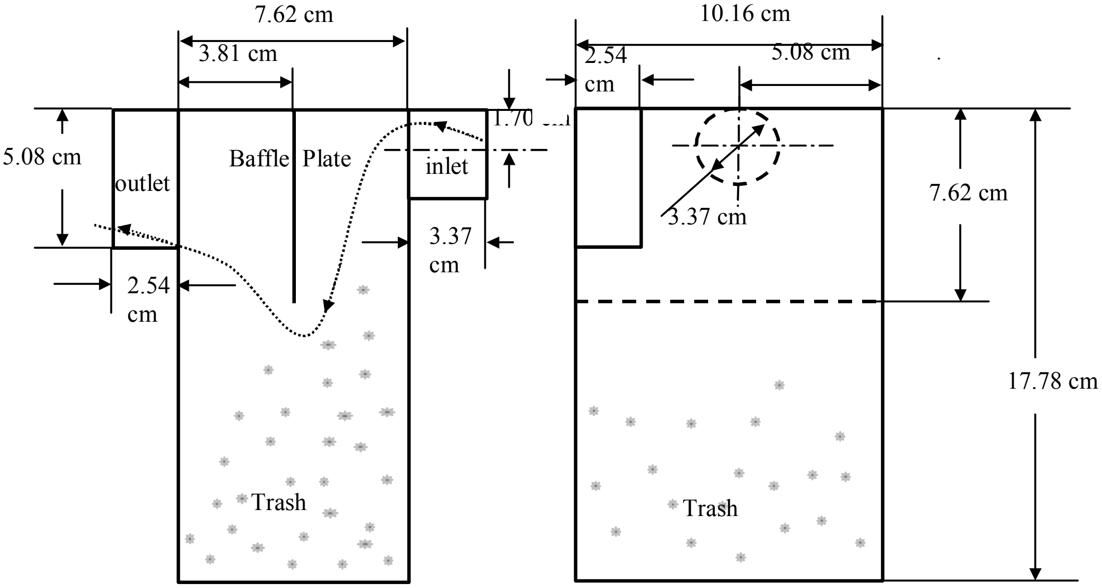

Figure 2. Baffle type pre-separator design and dimensions

(With the baffle-plate in the middle of the collection body)

Cyclones

The most common application of baffle type pre-separator/cyclone abatement systems utilizes 1D3D cyclones. The cyclones tested in this research were 1D3D and 1D2D cyclone designs. The diameters of the test cyclones were both 10.2 centimeters (4 inches). The D's in the 1D3D designation refer to the barrel diameter of the cyclone. The numbers preceding the D's relate the length of the barrel and cone sections, respectively. A 1D2D cyclone has a barrel length equal to the barrel diameter and a cone length of two times the barrel diameter, whereas the 1D3D cyclone has a barrel length equal to the barrel diameter and a cone length of three times the barrel diameter. These two cyclone designs and dimensions are illustrated in figure 3.

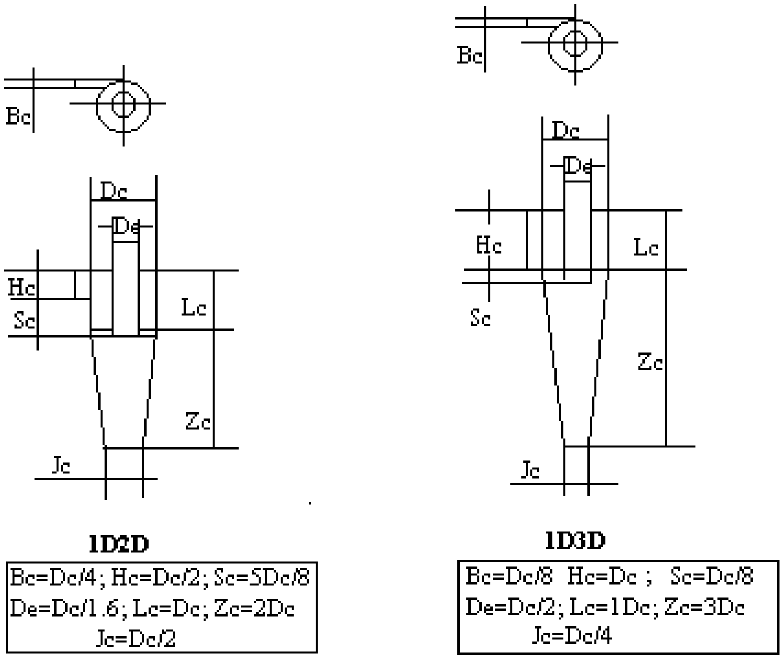

Figure 3. Cyclone designs and dimensions

Gin Trash

The ground gin trash used in this research was from USDA/ARS Cotton Production and Processing Research Unit in Lubbock, Texas. An air wash system was constructed to wash the trash in order to determine the fine dust (<100 µm) fractions of each test material and lint fiber content. The system consisted of a fine mesh (100 µm openings) screen box that was enclosed in a wooden box. A filter was placed on a filter holder between the wooden box and the fan/motor. The trash was sealed in the screen box and the wooden box was closed. The system was started and the fan pulled air through the system while the screen box rotated. Particulate matter less than 100µm was pulled through the fine mesh screen and accumulated on the filter. The screen box was rotated to allow all particles less than 100 µm to be separated out. By weighing the trash in the screen box before and after air washing, the fine dust (<100µm) contents in the trash were determined by dividing net fine dust weights by sample weights. After air wash, the lint fiber was manually picked out to determine the lint fiber content by dividing lint fiber weights by sample weights. The air wash results indicated that the fine dust and lint fiber content in the gin trash are 5.49 % and 10.35 %, respectively. Figure 4 shows the gin trash before and after air wash.

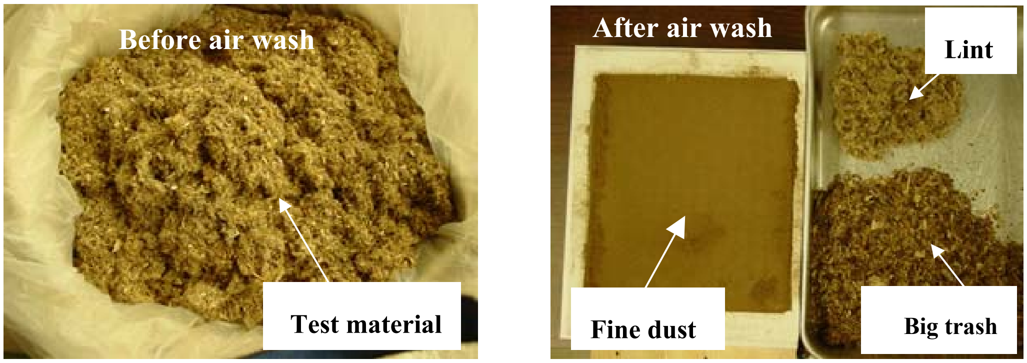

Figure 4. Gin trash: before and after air wash

Data Analyses

Two factors were tested in this experiment. These factors were (1) pre-separator plus cyclone systems and (2) inlet loading. ANOVA tests, using Tukey's Studentized Range (HSD) test at 95% confidence interval, were performed on the results.

Results and Discussions

Tests were conducted to determine and compare performances of two abatement strategies: (1) "pre-separator plus 1D3D cyclone" and (2) "pre-separator plus 1D2D" cyclone. The testing was replicated for two different inlet loading rates. The inlet loading rates were: (1) 27 g/m^3 (total) corresponding to a fine dust inlet loading rate of 1.5 g/m^3 and (2) 30 g/m^3 (total) corresponding to a fine dust inlet loading rate of 1.7 g/m^3. The test material, also known as total trash, includes big trash, fine dust (<100 µm) and lint fiber as shown in figure 4. Test results are included in tables 3-6 and in Figures 5-8.

Table 3. Test results - Pre-separator efficiencies (%) in the "pre-separator plus cyclone" systems

	Pre-separator + 1D2D[*]		Pre-separator +1D3D[**]	
	Inlet loading[***]		Inlet loading	
Test #	27 g/m^3	30 g/m^3	27 g/m^3	30 g/m^3
1	97.81	97.55	97.88	98.04
2	97.81	98.41	98.08	97.91
3	97.81	97.72	96.64	98.06
4	98.35	98.07	98.08	97.96
5	(Pipe clogging)[*****]	(Pipe clogging)	98.30	96.77
Average[****]	97.95^a	97.94^a	97.80^a	97.75^a

Table 4. Test results - cyclone efficiencies (%) in the "pre-separator plus cyclone" systems

	Pre-separator + 1D2D[*]		Pre-separator +1D3D[**]	
	Inlet loading[***]		Inlet loading	
Test #	27 g/m^3	30 g/m^3	27 g/m^3	30 g/m^3
1	96.86	97.23	97.14	97.52
2	96.05	96.01	97.40	97.29
3	95.01	95.48	97.08	97.21
4	96.42	96.72	97.80	97.25
5	(Pipe clogging)[*****]	(Pipe clogging)	97.38	97.65
Average[****]	96.09[b]	96.36[b]	97.36[a]	97.38[a]

Table 5. Test results - "pre-separator plus cyclone" system overall efficiencies (%)

	Pre-separator + 1D2D[*]		Pre-separator +1D3D[**]	
	Inlet loading[***]		Inlet loading	
Test #	27 g/m^3	30 g/m^3	27 g/m^3	30 g/m^3
1	99.93	99.93	99.94	99.95
2	99.91	99.94	99.95	99.95
3	99.89	99.88	99.90	99.95
4	99.94	99.94	99.96	99.94
5	(Pipe clogging)[*****]	(Pipe clogging)	99.96	99.92
Average[****]	99.92[c]	99.92[c]	99.94[c]	99.94[c]

Table 6. Test results - emission concentrations (mg/m^3)

	Pre-separator + 1D2D*		Pre-separator +1D3D**	
	Inlet loading***		Inlet loading	
Test #	27 g/m^3	30 g/m^3	27 g/m^3	30 g/m^3
1	18.87	20.34	16.55	14.53
2	23.74	18.59	13.65	16.96
3	29.92	37.05	26.84	16.23
4	16.18	18.97	11.54	16.86
5	(Pipe clogging)*****	(Pipe clogging)	12.18	22.73
Average****	22.18[d]	23.74[d]	16.15[d]	17.46[d]

* Flow rate in the 1D2D system was controlled at 0.016 m^3/s (33.3 ft^3/min.)

** Flow rate in the 1D3D system was controlled at 0.21 m^3/s (44.4 ft^3/min.)

*** Tests were conducted at two different inlet loading rates. These were controlled fine dust inlet loading rates of 1.5 and 1.7 g/m^3, corresponding to total trash loading rates of 27 and 30 g/m^3, respectively.

**** Means followed by the same letter are not significantly different at 0.05 level.

***** Pipe clogging problem happened at pre-separator inlet pipe connection part in the "pre-separator plus 1D2D cyclone" system. This problem was solved by changing inlet-conveying pipe to a smaller inner diameter. So, there was no chokage problem happened in "pre-separator plus 1D3D cyclone" system.

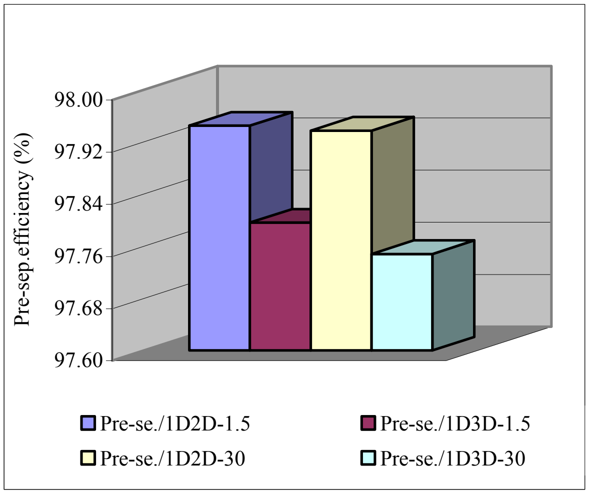

Figure 5. Pre-separator efficiency results.

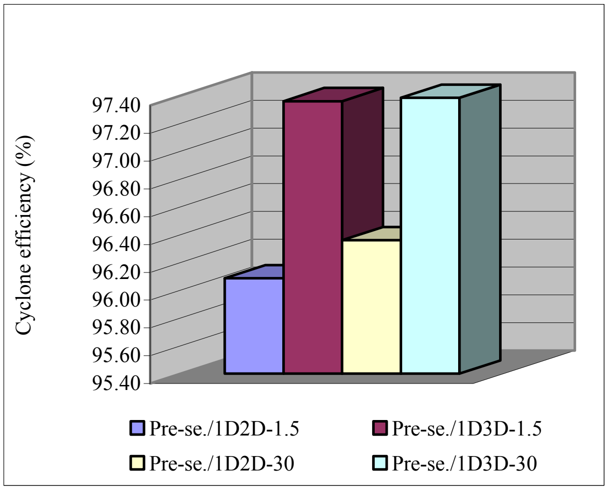

Figure 6. Cyclone efficiencies results.

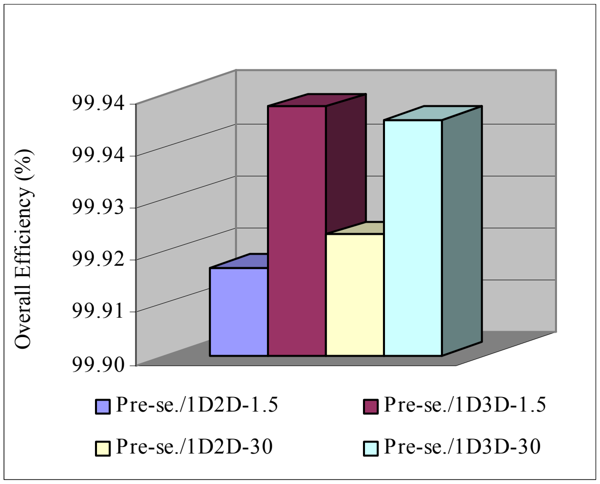

Figure 7. Overall efficiency results.

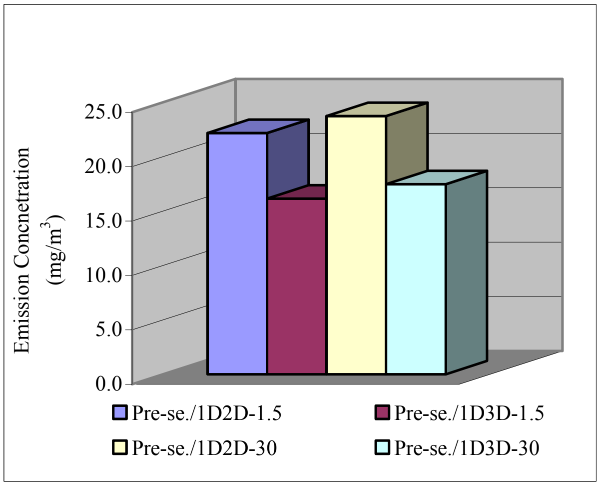

Figure 8. Emission concentration results.

Figure 5 is a summary of the test results for baffle type pre-separator. Even though the statistical analysis indicated no significant differences in efficiencies for baffle type pre-separator for the two abatement strategies (see table 3), there was a trend suggesting that the pre-separator was more efficient for the abatement system that included the 1D2D cyclone Compared to the system including the 1D3D cyclone (97.95 vs. 97.78%). This may be a consequence of the lower velocity in the chamber for the 1D2D system. The flow rate for the 1D2D system was less due to the 1D2D design velocity.

Figure 6 is a summary of the cyclone efficiency results. The 1D3D cyclone efficiencies were significantly higher than the 1D2D cyclone efficiencies results (96.2 vs. 97.4%). There is a possible affect of the slightly larger concentration entering the 1D3D cyclone compared to the 1D2D cyclone as a consequence of the slightly lower pre-separator efficiencies for the 1D3D abatement strategy. (See Figure 5.)

Figure 7 is a summary of the overall efficiencies of the two abatement strategies – baffle type pre-separator +1D2D and baffle type pre-separator +1D3D. The 1D3D system results tended to be more efficient although there were no significant differences in the overall performance of the two abatement strategies (99.92 vs. 99.94%).

Figure 8 summarizes the emission concentrations of the two systems. There was a trend for the 1D2D system to have a lower emission concentration although there were no significant differences in the overall performance of the two abatement strategies (17 vs. 23 mg/m^3)

Test results listed in tables 3 - 6 indicate that the baffle type pre-separator collected gin trash at over 97% efficiency for all test protocols. There was no statistical difference in pre-separator collection efficiencies for these two abatement strategies (1D2D and 1D3D systems), even though airflow rates and velocity in the systems were different. The overall collection efficiencies were in excess of 99%.

We were expecting difficulties with cycling lint in the 1D3D cyclone in these tests. With pre-separator in the system, the 1D3D cyclone system performed as well or better than the 1D2D system even though inlet concentrations contains relatively high concentrations of cotton lint.

Statistical analyses suggest that the overall efficiencies and emission concentrations from two testing systems are not significantly different, although "pre-separator plus 1D3D cyclone" system tends to have lower emission concentration. "Pre-separator plus 1D2D cyclone" system could perform as efficiently as "pre-separator plus 1D3D cyclone" system with inlet loadings of high lint content gin trash.

More tests are planned to make deeper comparison of these two systems with other kinds of gin trash, and to quantify the pre-separator impacts on both 1D2D and 1D3D cyclone performance.

Conclusion

"Pre-separator plus1D2D cyclone" and "pre-separator plus 1D3D cyclone" systems were tested with ground gin trash, containing 10.35% lint fiber and 5.49% fine dust (less than 100 µm). Test results indicate that the pre-separator collected gin trash at over 97% collection efficiency. There were no significant differences in emission concentrations and overall collection efficiencies from these two systems, even though the 1D3D cyclone collection efficiencies were slightly higher than 1D2D cyclone when tested with high lint content trash and with pre-separator in the system. "Pre-separator plus 1D2D cyclone" system could perform as efficiently as a "pre-separator plus 1D3D cyclone".

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