

USING CYCLONES EFFECTIVELY AT COTTON GINS

D. P. Whitelock, C. B. Armijo, M. D. Buser, S. E. Hughs

ABSTRACT. Cyclones are the most common type of emissions control device used in agricultural processing operations. Cyclones are efficient, reliable, low-cost, and require little maintenance. When used properly, cyclones effectively separate particulate matter from air streams, allowing compliance with state and federal air pollution regulations. Guidelines and techniques intended to help gin plant managers and operators determine if existing cyclones are correctly sized, properly constructed, and adequately maintained are reviewed. Methods presented are such that measurements can be made with minimal equipment and operating parameters determined with simple or no calculations.

Keywords. Cotton gins, Cyclones, Operation, Maintenance, Design, Recommendations.

Particulate emissions result from cotton ginning, where large amounts of air are used to convey seed cotton, seed, lint, and trash. In 1990, Congress amended the Clean Air Act which requires the U.S. Environmental Protection Agency (EPA) to set National Ambient Air Quality Standards (NAAQS) to limit certain pollutants to protect public health (Primary Standards) and public welfare (Secondary Standards). The EPA issued a revised NAAQS for particulate matter (PM) in October 2006 (Federal Register, 2006). The Primary Standards for fine particulate [particles with aerodynamic diameter less than or equal to 2.5 micrometers (PM_{2.5})] were revised to require that the three-year average of the 98th percentile of 24-h PM_{2.5} concentrations within any area must not exceed 35 micrograms per cubic meter (µg/m³). The standard requiring that the three-year average of the weighted annual mean PM_{2.5} concentrations for any area must not exceed 15 µg/m³ was retained. For particles with an aerodynamic diameter less than or equal to 10 micrometers (PM₁₀), the Primary Standard states that the mean 24-h PM₁₀ concentration for any area must not exceed 150 µg/m³ more than once per year on average over three years. There is currently no primary annual PM₁₀ standard. The Secondary Standards were set at the same levels as the Primary Standards.

States are required to attain and maintain air quality standards and enforce these standards through the permitting process. Agricultural operations, including cotton gins, are

most often required by the States to use reasonably available control technology (RACT) or best available control technology (BACT) to control emissions of particulate matter. The most common type of emissions control device used at cotton ginning plants is the cyclone (Parnell et al., 1994). Cyclones are efficient, reliable, low-cost, and require little maintenance. When properly sized, constructed, and maintained, cyclones can reduce a gin's emissions such that the state PM regulations can generally be met. This article is intended to be a tool for gin plant managers and operators. The information herein can be used to determine if cyclones are properly sized and how to properly size and construct cyclones. Further, this article contains information on how to maintain cyclones and information on when cyclones should be replaced.

CYCLONE OPERATION

The main purpose of a cyclone is to collect the trash and dust which results from the cleaning, conveying, and drying processes at agricultural facilities. The trash and dust laden conveying air enters the top of the cyclone and then spirals downward (fig. 1). Centrifugal force moves the trash and dust to the outside wall where they slide downward to the bottom of the cyclone to drop out of the trash exit. At the bottom of the cyclone the air reverses direction and moves upward in a smaller spiral to exit out the clean air exit at the top of the cyclone.

CYCLONE TYPES

The two most common types of cyclones used in agricultural applications are the 2D2D (Shepherd and Lapple, 1939) and 1D3D (Witz, 1979) designs (figs. 2-5). The first D in the designation indicates the length of the cyclone barrel relative to the cyclone barrel diameter and the second D indicates the length of the cyclone cone relative to the cyclone barrel diameter. Thus, the lengths of the barrel and the cone of 2D2D cyclones are equivalent to twice the cyclone barrel diameter. The 1D3D cyclones have a barrel length equal to the cyclone barrel diameter and a cone length equal to three times the cyclone barrel diameter. Note in

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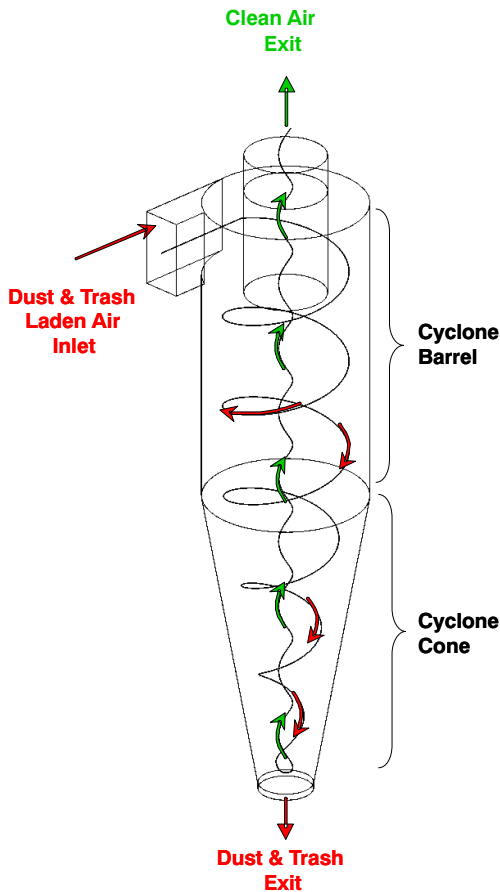


Figure 1. Cyclone operation.

figures 2 to 5 all dimensions are referenced to the diameter of the cyclone barrel. According to the literature (Parnell et al., 1994; Wang et al., 2002a, 2002b), 1D3D cyclones are slightly more efficient at separating fine particulates from an air stream than 2D2D cyclones, but require additional fan horsepower. For example, Parnell et al. (1994) stated that a 1D3D cyclone operated at a design inlet air velocity of 975.4 m/min (3200 ft/min) will typically have an associated pressure loss of 1145 Pa (4.6 in. H₂O) and a 2D2D cyclone operated at 914.4-m/min (3000-ft/min) design inlet air velocity will have a pressure loss of 921 Pa (3.7 in. H₂O).

The original designs of both the 2D2D cyclone (fig. 2) and the 1D3D cyclone (fig. 3) have trash outlet diameter equal to 1/4 the diameter of the cyclone barrel (D/4) and the original 1D3D design has a long narrow inlet (D long × D/8 wide). Improved cyclone designs (figs. 4 and 5) have been developed through research conducted at the USDA cotton ginning laboratories in Lubbock, Texas and Las Cruces, New Mexico. Research conducted by Baker and Hughs (1999) showed that using the 2D2D inlet design on a 1D3D cyclone reduced emissions, back pressure, and the incidences of choke-ups. This research also showed that increasing the trash outlet diameter on the 2D2D and 1D3D cyclones from 1/4 the diameter of the cyclone to 1/3 the diameter greatly reduced the incidences of choke-ups and improved the collection efficiency. Also, in situations where the cyclone will handle heavy trash loads, it is recommended that the trash exit diameter be no less than 30 cm (12 in.) to avoid cyclone choke-up. In situations where a cyclone sits directly

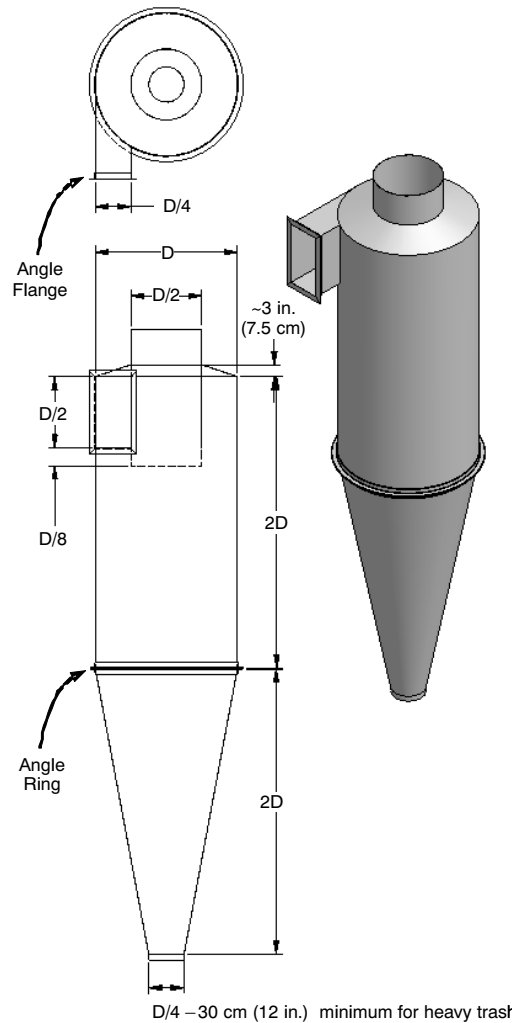


Figure 2. Original 2D2D cyclone design. All dimensions based on the main barrel diameter, D.

on top of an auger, belt conveyor, or trash house, an expansion chamber (fig. 6) may be added to the bottom of the cyclone to limit the recirculation of trash or dust at the bottom of the cyclone (Baker et al., 1997). This chamber helps control the vortex and allows the trash to separate and drop out of the air stream at the bottom of the cyclone more readily, reducing cyclone wear and improving cyclone efficiency. On the other hand, an expansion chamber would be of little benefit if a trunk line was used to pull a slight vacuum on the bottom of the cyclone to remove the material. When replacing existing cyclones or cyclone components, these enhancements should be considered. For example, when replacing the barrel of an existing 1D3D cyclone, a new barrel with the improved inlet is recommended. If the bottom section of an existing cyclone cone needs replacement, it is recommended that the old traditional section be replaced with one that includes the larger trash outlet and, if the situation warrants, an expansion chamber.

No matter the type of high efficiency cyclone used, 2D2D or 1D3D, cyclones must be sized correctly according to air flow rate, correctly configured for the application, and properly constructed and maintained to perform at optimum efficiency.

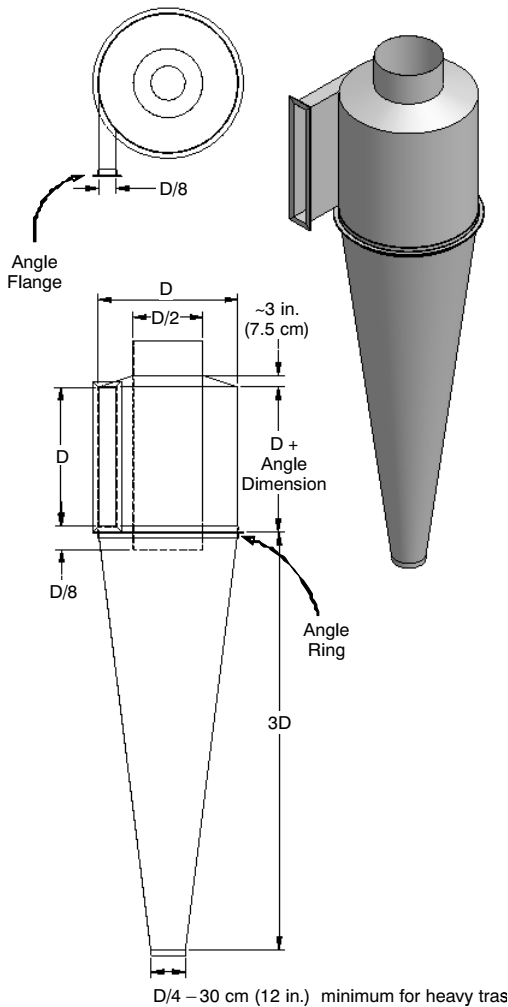


Figure 3. Original 1D3D cyclone design. All dimensions based on the main barrel diameter, D .

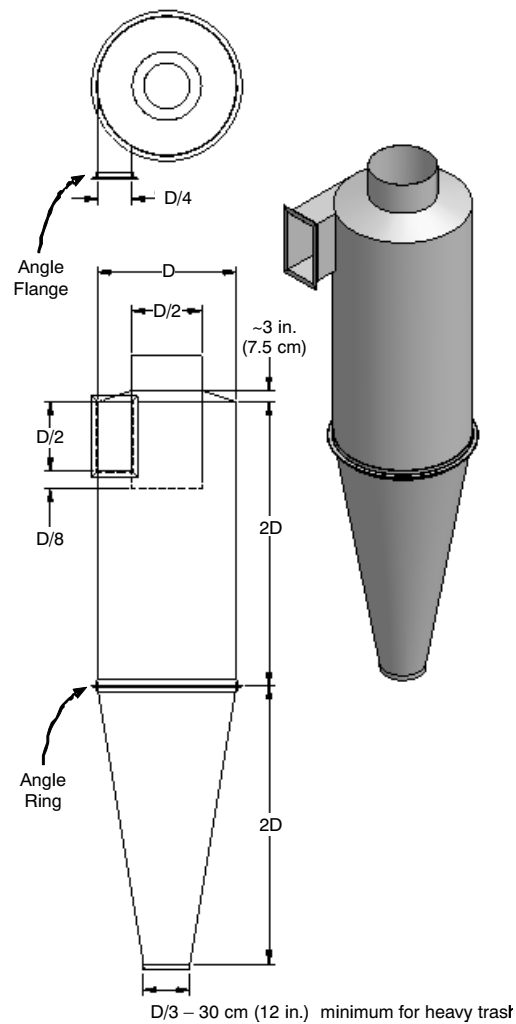


Figure 4. Improved 2D2D cyclone design. All dimensions based on the main barrel diameter, D .

AIR FLOW MEASUREMENTS

Large amounts of air are used to convey material throughout a cotton gin, and cyclone size is based on air flow rate. Thus it is important to understand air velocity and flow measurement. Some simple definitions are needed:

- Static pressure, measured in Pascals (Pa) [inches of water column (in. H_2O)], is the air pressure on the inside wall of the pipe that the fan must supply to overcome the resistance to airflow through the ductwork and components. Static pressure is usually negative before the fan inlet and positive after the fan outlet.
- Velocity pressure, measured in Pa (in. H_2O), is the pressure that results from air impacting on a fixed object. Velocity pressure is always positive.
- Total pressure, measured in Pa (in. H_2O), is the algebraic sum of static and velocity pressure.
- Air velocity, measured in meters per minute (m/min) [feet per minute (ft/min)], is the speed of the air moving through the pipe.
- Air flow, measured in cubic meters per min (m^3/min) [cubic feet per minute (ft³/min)], is the volume of air moving through the pipe per unit time.

Static, velocity, and total pressure are measured with a Pitot tube and a differential pressure gauge (fig. 7), two relatively inexpensive (~\$100 total) tools. A manometer can be used instead of a pressure gauge, but it is generally more awkward to manage than a gauge. Air velocity is calculated from velocity pressure, and air flow is determined by air velocity and area of the pipe. Air velocity and flow can be estimated from pipe size and velocity pressure using table 1.

MEASURING VELOCITY PRESSURE

Velocity pressure is ideally measured at least two pipe diameters upstream and eight pipe diameters downstream from any obstruction such as a fan, valve, or elbow. If this ideal situation is not possible, a long straight section of pipe should be sought and the measurement should be taken $\frac{3}{4}$ of the length of the straight pipe section downstream from the obstruction. A standard Pitot tube, 3-mm (1/8-in.) diameter \times 30.5-cm (12-in.) long, is used to measure velocity pressure in pipes up to 61 cm (24 in.) in diameter. For larger pipes, an 8-mm (5/16-in.) diameter and up to 152-cm (60-in.) long Pitot tube should be used. To insert the Pitot tube into the pipe, a hole about 1.5 mm (1/16 in.) larger than the Pitot tube should be drilled. For measuring velocity pressure, a differential pressure gauge, similar to the Magnehelic

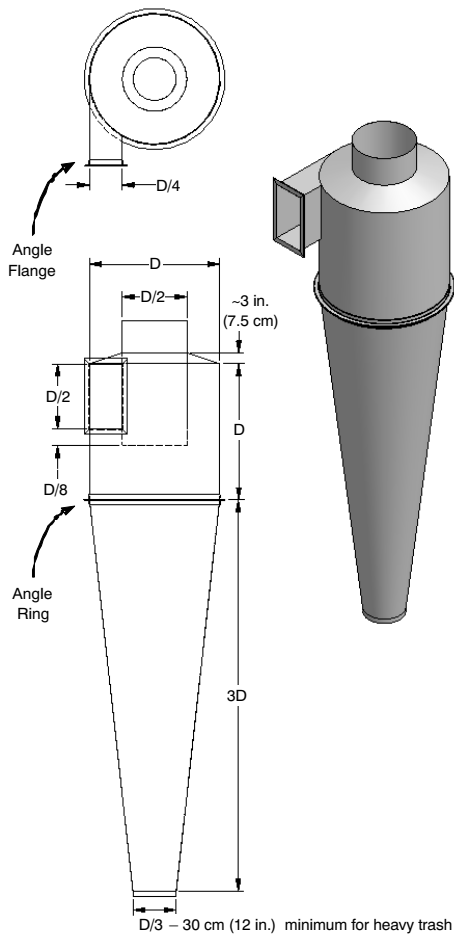


Figure 5. Improved 1D3D cyclone design. All dimensions based on the main barrel diameter, D.

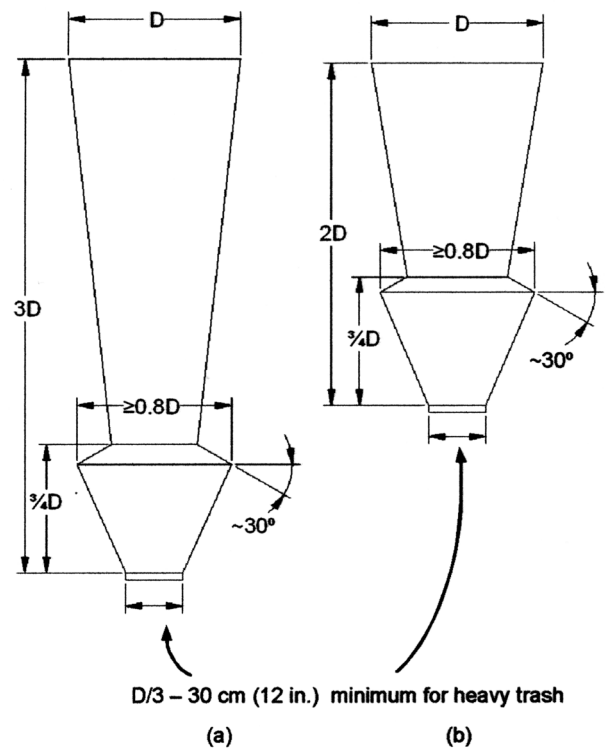


Figure 6. Expansion chamber on (a) 1D3D cone and (b) 2D2D cone. All dimensions based on the main barrel diameter, D.

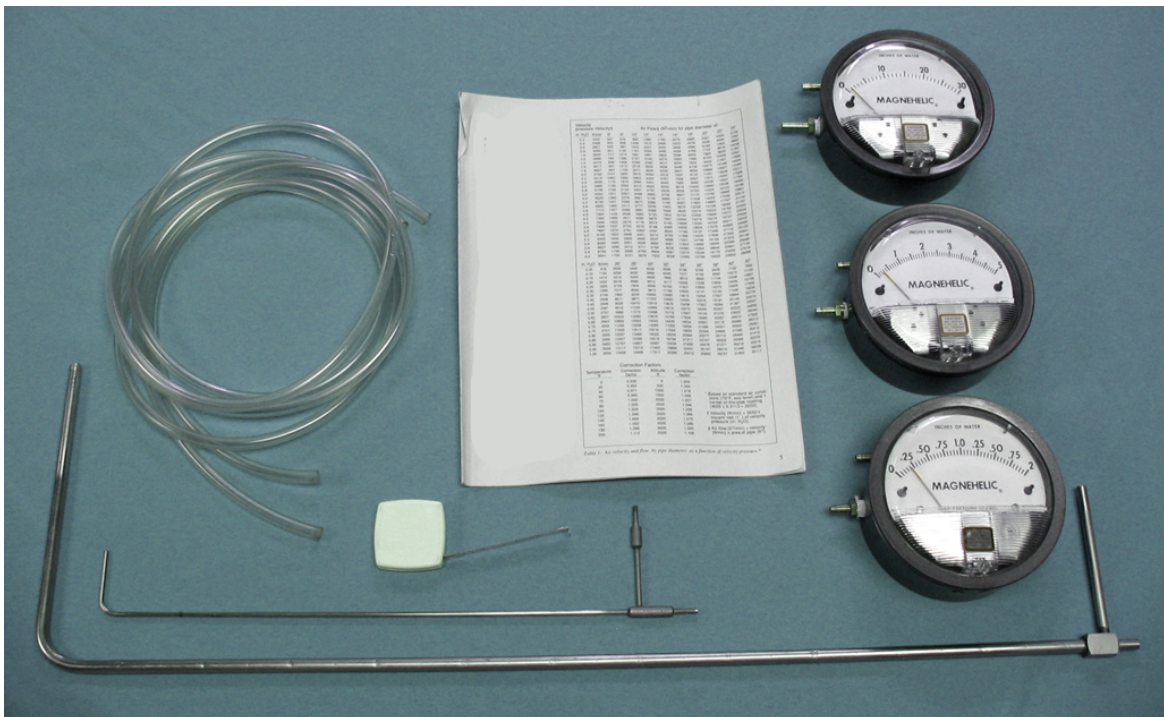


Figure 7. Recommended air measuring equipment: clockwise from right - pressure gauges [7.5, 1.2, and 0.5 kPa (30-, 5-, and 2-in. H₂O)]; Pitot tubes [8- and 3-mm (5/16- and 1/8-in.) diameter]; measuring tape; tubing; and copy of velocity pressure - air velocity - air flow rate relationships table.

Table 1a. Velocity pressure - air velocity - air flow rate relationships for various pipe diameters (metric units).

Velocity Pressure ^[a] (Pa)	Air Velocity ^[b] (m/min)	Air Flow Rate ^[b] (m ³ /min) for Pipe Diameter (cm)													
		15	20	25	30	35	40	45	50	55	60	65	70	75	80
25	353	6.2	11.1	17.3	24.9	33.9	44.3	56.1	69.2	83.8	99.7	117	136	156	177
50	499	8.8	15.7	24.5	35.3	48.0	62.7	79.3	97.9	118	141	165	192	220	251
75	611	10.8	19.2	30.0	43.2	58.8	76.8	97.1	120	145	173	203	235	270	307
100	705	12.5	22.2	34.6	49.9	67.9	88.6	112	138	168	199	234	271	312	355
125	789	13.9	24.8	38.7	55.7	75.9	99.1	125	155	187	223	262	303	348	396
150	864	15.3	27.1	42.4	61.1	83.1	109	137	170	205	244	287	332	382	434
175	933	16.5	29.3	45.8	65.9	89.8	117	148	183	222	264	310	359	412	469
200	997	17.6	31.3	49.0	70.5	96.0	125	159	196	237	282	331	384	441	501
225	1058	18.7	33.2	51.9	74.8	102	133	168	208	251	299	351	407	467	532
250	1115	19.7	35.0	54.7	78.8	107	140	177	219	265	315	370	429	493	561
275	1170	20.7	36.7	57.4	82.7	113	147	186	230	278	331	388	450	517	588
300	1222	21.6	38.4	60.0	86.3	118	154	194	240	290	345	405	470	540	614
325	1271	22.5	39.9	62.4	89.9	122	160	202	250	302	359	422	489	562	639
350	1319	23.3	41.5	64.8	93.3	127	166	210	259	313	373	438	508	583	663
375	1366	24.1	42.9	67.0	96.5	131	172	217	268	324	386	453	526	603	686
400	1411	24.9	44.3	69.2	99.7	136	177	224	277	335	399	468	543	623	709
425	1454	25.7	45.7	71.4	103	140	183	231	285	345	411	482	560	642	731
450	1496	26.4	47.0	73.4	106	144	188	238	294	355	423	496	576	661	752
475	1537	27.2	48.3	75.5	109	148	193	244	302	365	435	510	592	679	773
500	1577	27.9	49.5	77.4	111	152	198	251	310	375	446	523	607	697	793
525	1616	28.6	50.8	79.3	114	155	203	257	317	384	457	536	622	714	812
550	1654	29.2	52.0	81.2	117	159	208	263	325	393	468	549	637	731	831
575	1691	29.9	53.1	83.0	120	163	213	269	332	402	478	561	651	747	850
600	1728	30.5	54.3	84.8	122	166	217	275	339	410	488	573	665	763	868
625	1763	31.2	55.4	86.5	125	170	222	280	346	419	499	585	679	779	886
650	1798	31.8	56.5	88.3	127	173	226	286	353	427	508	597	692	794	904
675	1832	32.4	57.6	89.9	130	176	230	291	360	435	518	608	705	809	921
700	1866	33.0	58.6	91.6	132	180	234	297	366	443	528	619	718	824	938

		Air Flow Rate ^[b] (m ³ /min) for Pipe Diameter (cm)													
		85	90	95	100	105	110	115	120	125	130	135	140	145	150
12.5	249	141	159	177	196	216	237	259	282	306	331	357	384	412	441
25.0	353	200	224	250	277	305	335	366	399	433	468	505	543	582	623
37.5	432	245	275	306	339	374	410	449	488	530	573	618	665	713	763
50.0	499	283	317	353	392	432	474	518	564	612	662	714	768	823	881
62.5	558	316	355	395	438	483	530	579	631	684	740	798	858	921	985
75.0	611	347	389	433	480	529	580	634	691	750	811	874	940	1009	1079
87.5	660	374	420	468	518	571	627	685	746	810	876	944	1016	1089	1166
100.0	705	400	449	500	554	611	670	733	798	865	936	1009	1086	1165	1246
112.5	748	424	476	530	588	648	711	777	846	918	993	1071	1152	1235	1322
125.0	789	447	502	559	619	683	749	819	892	968	1047	1129	1214	1302	1393
137.5	827	469	526	586	650	716	786	859	935	1015	1098	1184	1273	1366	1461
150.0	864	490	550	612	678	748	821	897	977	1060	1146	1236	1330	1426	1526
162.5	899	510	572	637	706	778	854	934	1017	1103	1193	1287	1384	1485	1589
175.0	933	529	594	661	733	808	887	969	1055	1145	1238	1335	1436	1541	1649
187.5	966	548	614	685	758	836	918	1003	1092	1185	1282	1382	1487	1595	1707
200.0	997	566	635	707	783	864	948	1036	1128	1224	1324	1428	1535	1647	1763
212.5	1028	583	654	729	807	890	977	1068	1163	1262	1365	1472	1583	1698	1817
225.0	1058	600	673	750	831	916	1005	1099	1196	1298	1404	1514	1628	1747	1869
237.5	1087	617	691	770	854	941	1033	1129	1229	1334	1443	1556	1673	1795	1921
250.0	1115	633	709	790	876	966	1060	1158	1261	1368	1480	1596	1717	1841	1971

[a] Centerline velocity pressure reading.

[b] Based on standard air conditions at 21°C and 101.3 kPa.

Table 1b. Velocity pressure – air velocity – air flow rate relationships for various pipe diameters (U.S. customary units).

Velocity Pressure ^[a] (in. H ₂ O)	Air Velocity ^[b] (ft/min)	Air Flow Rate ^[b] (ft ³ /min) for Pipe Diameter (in.)													
		6	8	10	12	14	16	18	20	22	24	26	28	30	32
0.1	1154	227	403	630	907	1234	1612	2040	2518	3047	3626	4256	4936	5666	6446
0.2	1632	321	570	890	1282	1745	2279	2885	3561	4309	5128	6018	6980	8013	9117
0.3	1999	393	698	1090	1570	2137	2791	3533	4362	5277	6281	7371	8549	9813	11166
0.4	2308	453	806	1259	1813	2468	3223	4079	5036	6094	7252	8511	9871	11332	12893
0.5	2581	507	901	1408	2027	2759	3604	4561	5631	6813	8108	9516	11036	12669	14415
0.6	2827	555	987	1542	2221	3022	3948	4996	6168	7463	8882	10424	12090	13878	15790
0.7	3054	600	1066	1666	2398	3265	4264	5397	6662	8061	9594	11259	13058	14990	17056
0.8	3265	641	1140	1781	2564	3490	4558	5769	7122	8618	10256	12037	13960	16025	18233
0.9	3463	680	1209	1889	2720	3702	4835	6119	7554	9141	10878	12767	14807	16997	19339
1.0	3650	717	1274	1991	2867	3902	5096	6450	7963	9635	11467	13458	15608	17917	20385
1.1	3828	752	1336	2088	3007	4092	5345	6765	8352	10106	12026	14114	16369	18791	21380
1.2	3998	785	1396	2181	3140	4274	5583	7066	8723	10555	12561	14742	17097	19627	22331
1.3	4162	817	1453	2270	3269	4449	5811	7354	9079	10986	13074	15344	17795	20428	23243
1.4	4319	848	1508	2356	3392	4617	6030	7632	9422	11401	13568	15923	18467	21200	24120
1.5	4470	878	1560	2438	3511	4779	6242	7900	9753	11801	14044	16482	19115	21944	24967
1.6	4617	907	1612	2518	3626	4936	6446	8159	10073	12188	14504	17023	19742	22663	25786
1.7	4759	934	1661	2596	3738	5087	6645	8410	10383	12563	14951	17547	20350	23361	26579
1.8	4897	962	1709	2671	3846	5235	6837	8654	10684	12927	15384	18055	20940	24038	27350
1.9	5031	988	1756	2744	3951	5378	7025	8891	10976	13281	15806	18550	21514	24697	28099
2.0	5162	1014	1802	2815	4054	5518	7207	9122	11261	13626	16217	19032	22072	25338	28829
2.1	5289	1039	1846	2885	4154	5654	7385	9347	11540	13963	16617	19502	22618	25964	29541
2.2	5414	1063	1890	2953	4252	5787	7559	9567	11811	14291	17008	19961	23150	26575	30237
2.3	5535	1087	1932	3019	4348	5918	7729	9782	12077	14613	17390	20409	23670	27172	30916
2.4	5655	1110	1974	3084	4441	6045	7895	9992	12336	14927	17764	20848	24179	27757	31581
2.5	5771	1133	2015	3148	4533	6169	8058	10198	12591	15235	18131	21278	24678	28329	32232
2.6	5885	1156	2054	3210	4622	6292	8218	10400	12840	15536	18490	21700	25167	28890	32871
2.7	5998	1178	2094	3271	4710	6411	8374	10599	13085	15832	18842	22113	25646	29440	33497
2.8	6108	1199	2132	3331	4797	6529	8528	10793	13325	16123	19188	22519	26117	29981	34111
2.9	6216	1220	2170	3390	4882	6645	8679	10984	13561	16408	19527	22917	26579	30511	34715
3.0	6322	1241	2207	3448	4965	6758	8827	11172	13792	16689	19861	23309	27033	31033	35309

		Air Flow Rate ^[b] (ft ³ /min) for Pipe Diameter (in.)													
		34	36	38	40	42	44	46	48	50	52	54	56	58	60
0.05	816	5146	5769	6428	7122	7852	8618	9419	10256	11129	12037	12981	13960	14975	16025
0.10	1154	7277	8159	9090	10073	11105	12188	13321	14504	15738	17023	18357	19742	21178	22663
0.15	1414	8913	9992	11134	12336	13601	14927	16315	17764	19276	20848	22483	24179	25937	27757
0.20	1632	10292	11538	12856	14245	15705	17236	18839	20512	22257	24074	25961	27920	29950	32051
0.25	1825	11507	12900	14373	15926	17559	19271	21062	22934	24885	26915	29025	31215	33485	35834
0.30	1999	12605	14131	15745	17446	19234	21110	23073	25123	27260	29484	31796	34195	36681	39254
0.35	2159	13615	15264	17007	18844	20776	22801	24921	27135	29444	31846	34343	36934	39620	42399
0.40	2308	14555	16318	18181	20145	22210	24376	26642	29009	31477	34045	36715	39484	42355	45327
0.45	2448	15438	17307	19284	21367	23557	25854	28258	30769	33386	36110	38942	41880	44924	48076
0.50	2581	16273	18244	20327	22523	24832	27253	29787	32433	35192	38064	41048	44145	47354	50677
0.55	2707	17067	19134	21319	23622	26044	28583	31240	34016	36910	39922	43052	46300	49666	53150
0.60	2827	17826	19985	22267	24673	27202	29854	32630	35529	38551	41697	44966	48358	51874	55513
0.65	2943	18554	20801	23176	25680	28312	31073	33962	36979	40125	43399	46802	50333	53992	57780
0.70	3054	19254	21586	24051	26650	29381	32246	35244	38375	41640	45038	48569	52233	56031	59961
0.75	3161	19930	22344	24895	27585	30412	33378	36481	39722	43101	46618	50273	54066	57997	62066
0.80	3265	20584	23077	25712	28490	31410	34472	37677	41025	44515	48147	51922	55839	59899	64101
0.85	3365	21217	23787	26503	29366	32376	35533	38837	42288	45885	49629	53520	57558	61743	66074
0.90	3463	21832	24476	27271	30218	33315	36563	39963	43513	47215	51068	55072	59227	63533	67990
0.95	3558	22431	25147	28019	31046	34228	37565	41058	44706	48509	52467	56581	60850	65274	69853
1.00	3650	23013	25800	28747	31852	35117	38541	42125	45867	49769	53830	58051	62430	66969	71668

[a] Centerline velocity pressure reading.

[b] Based on standard air conditions at 70°F and 29.92-in. Hg.

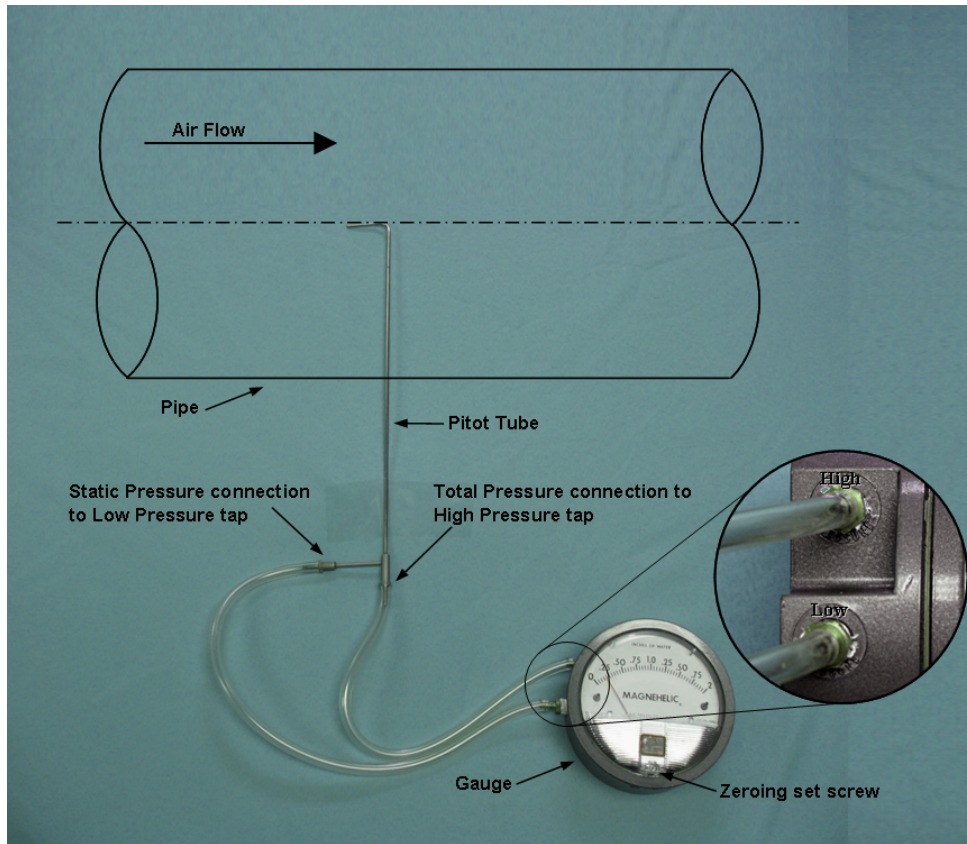


Figure 8. Measuring centerline velocity pressure with a Pitot tube and gauge.

differential pressure gauges (Dwyer Instruments, Michigan City, Ind.) shown in figures 7 and 8, is typically used. The differential pressure gauge tap marked “high pressure” should be connected with tubing to the total pressure connection that is an extension of the main tube of the Pitot tube, and the “low pressure” tap on the gauge should be connected to the static pressure connection that branches off perpendicularly to the main tube of the Pitot tube (fig. 8). The pressure gauge should be held vertically and should be zeroed with the set screw on the front. Insert the Pitot tube with the opening pointing against the air flow and check for uniform air velocity by observing that the velocity pressure is near zero at the near wall, reaches a maximum at the pipe center, and falls to near zero at the far wall. If the velocity pressure does not behave accordingly, then the flow is not uniform and a different straight section of pipe should be used for the measurement. Place the Pitot tube in the center of the pipe to take the velocity pressure reading. While measuring velocity pressure, the pressure gauge may fluctuate; estimate the average reading. Pitot measurements cannot be made in lines that are loaded with seed cotton, lint, or trash. For these lines, stop the material flow and then take the measurement. Air measurements should be taken with burners for drying systems turned off. From time to time systems may be operated without burners, thus air readings need to be taken “cold” to ensure that adequate air flow is maintained. Also, careful attention should be paid to not plug up or damage the Pitot tube and to avoid dangerous situations while measuring.

Once velocity pressure and pipe diameter have been measured, use table 1 to determine air velocity and air flow rate in the pipe. Find the measured velocity pressure in the

first column. The value in the same row in the second column corresponds to the air velocity. Find the pipe diameter in the top row. The intersection of the velocity pressure row and the pipe diameter column will result in the air flow rate for that air velocity and pipe diameter. Note that table 1 gives the average velocity based on one center-of-the-pipe reading of velocity pressure for standard air (21°C and 101.3 kPa or 70°F and 29.92-in. Hg). Thus, to obtain corrected velocities and flow rates for conditions other than standard, a correction factor can be obtained by finding the intersection of the air temperature row and elevation above sea level column in table 2. This correction factor is then multiplied by the air velocity and flow rate determined from table 1.

CYCLONE SIZE EVALUATION

Following is an example, using metric units, of how to determine if cyclones have been sized correctly. In this example, numbers in parentheses “()” are not U.S. customary unit equivalents, but instead are similar values representing more typical numbers that might be encountered when working with cyclone systems that were designed using U.S. customary units. For cyclone sizes and measurements based on U.S. customary units the method would be identical, using the correct tables for U.S. customary units. A 60-cm (24-in.) pipe, carrying the exhaust from an incline cleaner, discharges into double 120-cm (48-in.) 1D3D cyclones. The gin is located at 1200-m (4000-ft) elevation. Using a Pitot tube and gauge, the measured velocity pressure was 300 Pa (1.2-in. H₂O) and the air temperature was 5°C (40°F). Table 1 shows that 300 Pa (1.2-in. H₂O) velocity pressure corresponds to

Table 2a. Temperature and elevation corrections for air velocity and air flow (metric units).

Air Temperature (°C)	Elevation Above Sea Level (m)											
	0	150	300	450	600	750	900	1050	1200	1350	1500	1650
-15	0.937	0.945	0.953	0.962	0.970	0.979	0.987	0.996	1.004	1.013	1.022	1.031
-10	0.946	0.954	0.962	0.971	0.979	0.988	0.997	1.005	1.014	1.023	1.032	1.041
-5	0.955	0.963	0.972	0.980	0.989	0.997	1.006	1.015	1.024	1.033	1.042	1.051
0	0.964	0.972	0.981	0.989	0.998	1.007	1.015	1.024	1.033	1.042	1.051	1.061
5	0.972	0.981	0.990	0.998	1.007	1.016	1.025	1.034	1.043	1.052	1.061	1.070
10	0.981	0.990	0.998	1.007	1.016	1.025	1.034	1.043	1.052	1.061	1.070	1.080
15	0.990	0.998	1.007	1.016	1.025	1.034	1.043	1.052	1.061	1.070	1.080	1.089
21	1.000 ^[a]	1.009	1.018	1.026	1.035	1.045	1.054	1.063	1.072	1.082	1.091	1.101
25	1.007	1.016	1.024	1.033	1.042	1.052	1.061	1.070	1.079	1.089	1.098	1.108
30	1.015	1.024	1.033	1.042	1.051	1.060	1.070	1.079	1.088	1.098	1.108	1.117
35	1.024	1.032	1.042	1.051	1.060	1.069	1.078	1.088	1.097	1.107	1.117	1.126
40	1.032	1.041	1.050	1.059	1.068	1.078	1.087	1.097	1.106	1.116	1.126	1.136
45	1.040	1.049	1.058	1.068	1.077	1.086	1.096	1.105	1.115	1.125	1.135	1.145
50	1.048	1.057	1.067	1.076	1.085	1.095	1.104	1.114	1.124	1.134	1.144	1.154
55	1.056	1.065	1.075	1.084	1.094	1.103	1.113	1.123	1.132	1.142	1.152	1.162
60	1.064	1.074	1.083	1.092	1.102	1.112	1.121	1.131	1.141	1.151	1.161	1.171
65	1.072	1.082	1.091	1.101	1.110	1.120	1.130	1.140	1.150	1.160	1.170	1.180
70	1.080	1.090	1.099	1.109	1.118	1.128	1.138	1.148	1.158	1.168	1.178	1.189
75	1.088	1.097	1.107	1.117	1.126	1.136	1.146	1.156	1.166	1.177	1.187	1.197
80	1.096	1.105	1.115	1.125	1.135	1.144	1.154	1.165	1.175	1.185	1.195	1.206
85	1.103	1.113	1.123	1.133	1.143	1.153	1.163	1.173	1.183	1.193	1.204	1.214
90	1.111	1.121	1.131	1.141	1.150	1.161	1.171	1.181	1.191	1.202	1.212	1.223
95	1.119	1.129	1.138	1.148	1.158	1.169	1.179	1.189	1.199	1.210	1.221	1.231
100	1.126	1.136	1.146	1.156	1.166	1.176	1.187	1.197	1.208	1.218	1.229	1.240

^[a] Base value for standard air (21°C and 101.3 kPa)

Table 2b. Temperature and elevation corrections for air velocity and air flow (U.S. customary units).

Air Temperature (°F)	Elevation above Sea Level (ft)											
	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500
0	0.932	0.940	0.948	0.957	0.965	0.974	0.982	0.991	1.000	1.009	1.018	1.027
10	0.942	0.950	0.958	0.967	0.976	0.984	0.993	1.002	1.011	1.020	1.029	1.038
20	0.952	0.960	0.969	0.977	0.986	0.995	1.004	1.012	1.021	1.030	1.040	1.049
30	0.962	0.970	0.979	0.987	0.996	1.005	1.014	1.023	1.032	1.041	1.050	1.060
40	0.971	0.980	0.989	0.997	1.006	1.015	1.024	1.033	1.042	1.052	1.061	1.071
50	0.981	0.990	0.998	1.007	1.016	1.025	1.034	1.044	1.053	1.062	1.072	1.081
60	0.991	0.999	1.008	1.017	1.026	1.035	1.045	1.054	1.063	1.073	1.082	1.092
70	1.000 ^[a]	1.009	1.018	1.027	1.036	1.045	1.055	1.064	1.073	1.083	1.092	1.102
80	1.009	1.018	1.027	1.037	1.046	1.055	1.064	1.074	1.083	1.093	1.103	1.113
90	1.019	1.028	1.037	1.046	1.055	1.065	1.074	1.084	1.093	1.103	1.113	1.123
100	1.028	1.037	1.046	1.056	1.065	1.074	1.084	1.094	1.103	1.113	1.123	1.133
110	1.037	1.046	1.056	1.065	1.074	1.084	1.094	1.103	1.113	1.123	1.133	1.143
120	1.046	1.055	1.065	1.074	1.084	1.093	1.103	1.113	1.123	1.133	1.143	1.153
130	1.055	1.064	1.074	1.083	1.093	1.103	1.113	1.123	1.132	1.143	1.153	1.163
140	1.064	1.073	1.083	1.093	1.102	1.112	1.122	1.132	1.142	1.152	1.162	1.173
150	1.073	1.082	1.092	1.102	1.112	1.121	1.131	1.141	1.152	1.162	1.172	1.183
160	1.082	1.091	1.101	1.111	1.121	1.131	1.141	1.151	1.161	1.171	1.182	1.192
170	1.090	1.100	1.110	1.120	1.130	1.140	1.150	1.160	1.170	1.181	1.191	1.202
180	1.099	1.109	1.119	1.128	1.139	1.149	1.159	1.169	1.180	1.190	1.201	1.211
190	1.107	1.117	1.127	1.137	1.147	1.158	1.168	1.178	1.189	1.199	1.210	1.221
200	1.116	1.126	1.136	1.146	1.156	1.166	1.177	1.187	1.198	1.208	1.219	1.230
210	1.124	1.134	1.144	1.155	1.165	1.175	1.186	1.196	1.207	1.218	1.228	1.239

^[a] Base value for standard air (70°F and 29.92-in. Hg.)

about 1222 m/min (3998 ft/min) air velocity and that the intersection of the velocity pressure row and the 60-cm (24-in.) pipe diameter column indicate a flow rate of 345 m³/min (12,561 ft³/min) of air. From table 2, the correction factor from the intersection of the 5°C (40°F) air temperature row and the 1200-m (4000-ft) elevation above sea level column is 1.043 (1.042). Thus, the corrected air flow rate would be 345 m³/min × 1.043 = 360 m³/min (12,561 ft³/min × 1.042 = 13,089 ft³/min). Table 3 shows the recommended 1D3D cyclone sizes and arrangements as a function of total air flow. Since the system in question has double 120-cm (48-in.) cyclones, the double cyclone column is followed down to 120-cm (48-in.) diameter and then over to the air flow rate column to reveal that double 120-cm (48-in.) 1D3D cyclones are recommended for air flows up to 360 m³/min (13,000 ft³/min). The next row down shows that double 125-cm (50-in.) 1D3D cyclones are recommended for air flows up to 380 m³/min (14,000 ft³/min). Since the corrected airflow of 360 m³/min (13,089 ft³/min) agrees with the recommended airflow (is only slightly over the recommended airflow of 13,000 ft³/min), the double 120-cm (48-in.) cyclones are acceptable and, therefore, the cyclones are sized correctly. Since many 2D2D cyclones are in use, table 4 shows the recommended cyclone arrangements for 2D2D cyclones.

The design process for selecting cyclones is discussed in Appendix 1.

CYCLONE CONSTRUCTION

Cyclone construction is important to efficient operation. The transitions and metal gauge must match the particular use and the interior finish needs to be of the highest quality.

Transitions from round air ducts to rectangular cyclone inlets vary with cyclone type and application. The transition for the improved (and recommended) 1D3D and all 2D2D cyclone designs either has the top of the transition flush with the top of conveying duct and the top of the cyclone inlet or all three are aligned along the centerline of the conveying duct as shown in figure 9a. The transition for the original 1D3D cyclone used to collect dust and other fine particulate also has the top of the transition flush with the tops of both the conveying duct and cyclone inlet while the bottom of the transition angles downward to the bottom of the inlet (fig. 9b). The transition on an original 1D3D cyclone used to collect trash and other large debris must be a different type. For this application, the bottom of the transition must be flush with the bottom of both the conveying duct and cyclone inlet and the top of the transition angles upward to the top of the inlet (fig. 9c). If the transition on an original design 1D3D used for trash is not installed in this way, trash will collect in the bottom of the transition and may choke-up.

Proper metal gauge is important to cyclone life. Typically 2.5-mm (12-gauge) metal is used for cyclones handling trash and debris, while 1.5-mm (16-gauge) metal is used for cyclones handling fine particulate only. Occasionally, 1.5-mm (16-gauge) metal may be used for trash collection cyclones, but the service life of these cyclones tends to be shorter because of lighter metal gauge construction.

Construction techniques and interior surface finish impact collection efficiency. Any obstruction or surface roughness on the inner surfaces of the cyclone will cause turbulence

Table 3a. Recommended 1D3D cyclone diameter^[a] (metric units).

Air Flow Rate ^[b] (m ³ /min)	Cyclone Diameter ^[c] (cm) for Cyclone Multiples		
	Single	Double	Quads
20	40	---	---
30	50	---	---
40	55	40	---
50	65	45	---
60	70	50	---
70	75	55	40
80	80	55	40
90	85	60	45
100	90	65	45
110	95	65	45
120	100	70	50
140	105	75	55
150	110	80	55
160	115	80	55
180	120	85	60
190	125	90	60
210	130	95	65
230	135	95	70
240	140	100	70
260	145	105	75
280	150	105	75
300	155	110	80
320	160	115	80
340	165	120	85
360	170	120	85
380	175	125	90
400	180	130	90
420	185	130	95
450	190	135	95
470	195	140	100
490	200	140	100
530	---	145	105
560	---	150	105
600	---	155	110
640	---	160	115
680	---	165	120
720	---	170	120
760	---	175	125
810	---	180	130
850	---	185	130
900	---	190	135
950	---	195	140
990	---	200	140
1060	---	---	145
1130	---	---	150
1200	---	---	155
1280	---	---	160
1360	---	---	165
1450	---	---	170
1530	---	---	175
1620	---	---	180
1710	---	---	185
1800	---	---	190
1900	---	---	195
1990	---	---	200

[a] Inlet air velocity = 975.4 m/min.

[b] If air volume falls between values round to the nearest or next higher volume.

[c] Cyclone diameters rounded to the nearest 5 cm.

Table 3b. Recommended 1D3D cyclone diameter^[a] (U.S. customary units).

Air Flow Rate ^[b] (ft ³ /min)	Cyclone Diameter ^[c] (in.) for Cyclone Multiples		
	Single	Double	Quadruple
1000	18	---	---
1500	24	---	---
2000	26	18	---
2500	30	22	---
3000	32	24	---
3500	36	26	18
4000	38	26	18
4500	40	28	20
5000	42	30	22
5500	44	32	22
6000	46	32	24
6500	48	34	24
7000	50	36	26
7500	52	36	26
8000	54	38	26
9000	56	40	28
9500	58	42	30
10000	60	42	30
11000	62	44	32
11500	64	46	32
12000	66	46	32
13000	68	48	34
14000	70	50	36
14500	72	52	36
15500	74	52	38
16000	76	54	38
17000	78	56	40
18000	80	56	40
19000	---	58	42
20500	---	60	42
22000	---	62	44
23000	---	64	46
24500	---	66	46
26000	---	68	48
28000	---	70	50
29500	---	72	52
31000	---	74	52
32500	---	76	54
34500	---	78	56
36000	---	80	56
38500	---	---	58
41000	---	---	60
44000	---	---	62
46500	---	---	64
49500	---	---	66
52500	---	---	68
56000	---	---	70
59000	---	---	72
62000	---	---	74
65500	---	---	76
69000	---	---	78
72500	---	---	80

[a] Inlet air velocity = 3200 ft/min.

[b] If measured air flow rate falls between values round to the nearest or next higher flow rate.

[c] Cyclone diameters rounded to the nearest 2 in.

Table 4a. Recommended 2D2D cyclone diameter^[a] (metric units).

Air Flow Rate ^[b] (m ³ /min)	Cyclone Diameter ^[c] (cm) for Cyclone Multiples		
	Single	Double	Quadruple
20	40	---	---
30	50	---	---
40	60	40	---
50	65	45	---
60	70	50	---
70	80	55	40
80	85	60	40
90	90	65	45
100	95	65	45
120	100	70	50
130	105	75	55
140	110	80	55
150	115	80	55
170	120	85	60
180	125	90	65
200	130	95	65
210	135	95	70
230	140	100	70
240	145	100	70
260	150	105	75
280	155	110	80
300	160	115	80
320	165	120	85
340	170	120	85
360	175	125	90
380	180	130	90
400	185	130	95
420	190	135	95
440	195	140	100
460	200	140	100
490	---	145	105
530	---	150	110
560	---	155	110
600	---	160	115
640	---	165	120
680	---	170	120
720	---	175	125
760	---	180	130
800	---	185	130
840	---	190	135
890	---	195	140
930	---	200	145
990	---	---	145
1060	---	---	150
1130	---	---	155
1200	---	---	160
1280	---	---	165
1360	---	---	170
1440	---	---	175
1520	---	---	180
1600	---	---	185
1690	---	---	190
1780	---	---	195
1870	---	---	200

[a] Inlet air velocity = 914.4 m/min.

[b] If air volume falls between values round to the nearest or next higher volume.

[c] Cyclone diameters rounded to the nearest 5 cm.

**Table 4b. Recommended 2D2D cyclone diameter^[a]
(U.S. customary units).**

Air Flow Rate ^[b] (ft ³ /min)	Cyclone Diameter ^[c] (in.) for Cyclone Multiples		
	Single	Double	Quadruple
1000	20	---	---
1500	24	---	---
2000	28	20	---
2500	30	22	---
3000	34	24	---
3500	36	26	18
4000	40	28	20
4500	42	30	20
5000	44	30	22
5500	46	32	22
6000	48	34	24
6500	50	36	24
7000	52	36	26
7500	54	38	26
8000	56	40	28
9000	58	42	30
9500	60	42	30
10000	62	44	30
11000	64	46	32
11500	66	46	34
12000	68	48	34
13000	70	50	36
13500	72	50	36
14500	74	52	38
15000	76	54	38
16000	78	56	40
17000	80	58	40
18000	---	58	42
19000	---	60	42
20500	---	62	44
22000	---	64	46
23000	---	66	46
24500	---	68	48
26000	---	70	50
27500	---	72	52
29000	---	74	52
30500	---	76	54
32500	---	78	56
34000	---	80	58
36000	---	---	58
38500	---	---	60
41000	---	---	62
44000	---	---	64
46500	---	---	66
49500	---	---	68
52500	---	---	70
55500	---	---	72
58500	---	---	74
61500	---	---	76
65000	---	---	78
68000	---	---	80

^[a] Inlet air velocity = 3000 ft/min.

^[b] If air volume falls between values round to the nearest or next higher volume.

^[c] Cyclone diameters rounded to the nearest 2 in.

which will re-entrain dust by taking it away from the wall, towards the center of the cyclone. This causes more of the dust to be carried out the top of the cyclone, increasing emissions. The curved sides of the cyclone bodies and cone

sections should be formed by rolling rather than by step breaking or cord breaking (fig. 10). Cyclones that are formed by step breaking are not exactly round – each slight bend increases surface roughness. Seams should be air-tight and smooth on the inner surface of the cyclones. Ideally, seams should be butt welded, not lapped, and ground smooth on the inside surfaces. If the barrel-to-cone connection is not flush with the side of the cyclone (fig. 10), the resulting step forms an obstruction to smooth air flow. Lastly, the cyclone must be built to dimension. A tolerance of ± 0.5 in. on the diameter is acceptable, but the inside of the cyclone must be smooth and flush.

Although every dimension on a cyclone is designed to be proportional to the diameter of the cyclone, there are times when construction techniques require a modification. This can be acceptable, as long as the critical tolerances are maintained. The size of the inlet and the air and trash outlets are critical and must be made as close to specifications as possible by the fabricator. The air outlet tube must also extend below the bottom of the inlet on the inside of the cyclone. On the other hand, slight variations in the length of the cyclone barrel or cone to accommodate construction methods are acceptable. For example, if the cyclone is constructed with a 1.5-in. (40-mm) angle iron ring at the top and bottom of the barrel, then the height of the barrel must be increased by the dimension of the angle iron to include it at the top above the air entrance. As long as the inlet and air outlet dimensions are maintained, then the additional barrel height is acceptable.

Notice in figures 2 through 5 the slope of the top of the cyclone. This slope makes both the cyclone and air outlet sturdier while also allowing water to run off the top of the cyclone.

CYCLONE MAINTENANCE

Although cyclones require little maintenance, there are a few items that require attention to ensure maximum cyclone efficiency. First, check for air leaks (fig. 11). Leaks in cyclones and piping can be caused by daily abrasion. During normal operation, air leaks are generally easier to locate as dust can be emitted from the wear holes or transition and pipe joints where the air leaks occur. Air leaks can often be sealed by installing new gasket material or sealants. Leaks should be repaired immediately as they may affect cyclone airflow, thus reducing efficiency, and they emit particulate as fugitive dust. Second, check the smoothness on the inside of the cyclone. As mentioned earlier, cyclones operate most efficiently when there are no obstructions (even a seam weld) to interrupt the material flow. Cyclones that have been dented should be replaced (fig. 11). Finally, check cyclones for choke ups (material retained in the cyclone preventing it from operating normally) on a regular basis. Periodically checking the air velocities entering the cyclones (when the system is not processing material) and comparing these values to the design velocities is a good method of checking for system choke-ups. Choke-ups will happen and may not affect the plants processing rate, but they will greatly affect the efficiency of the cyclones. For example, a cyclone trash exit can choke and the cyclone will begin to fill with debris, effectively reducing the efficiency to zero, while air may still flow freely through the cyclone.

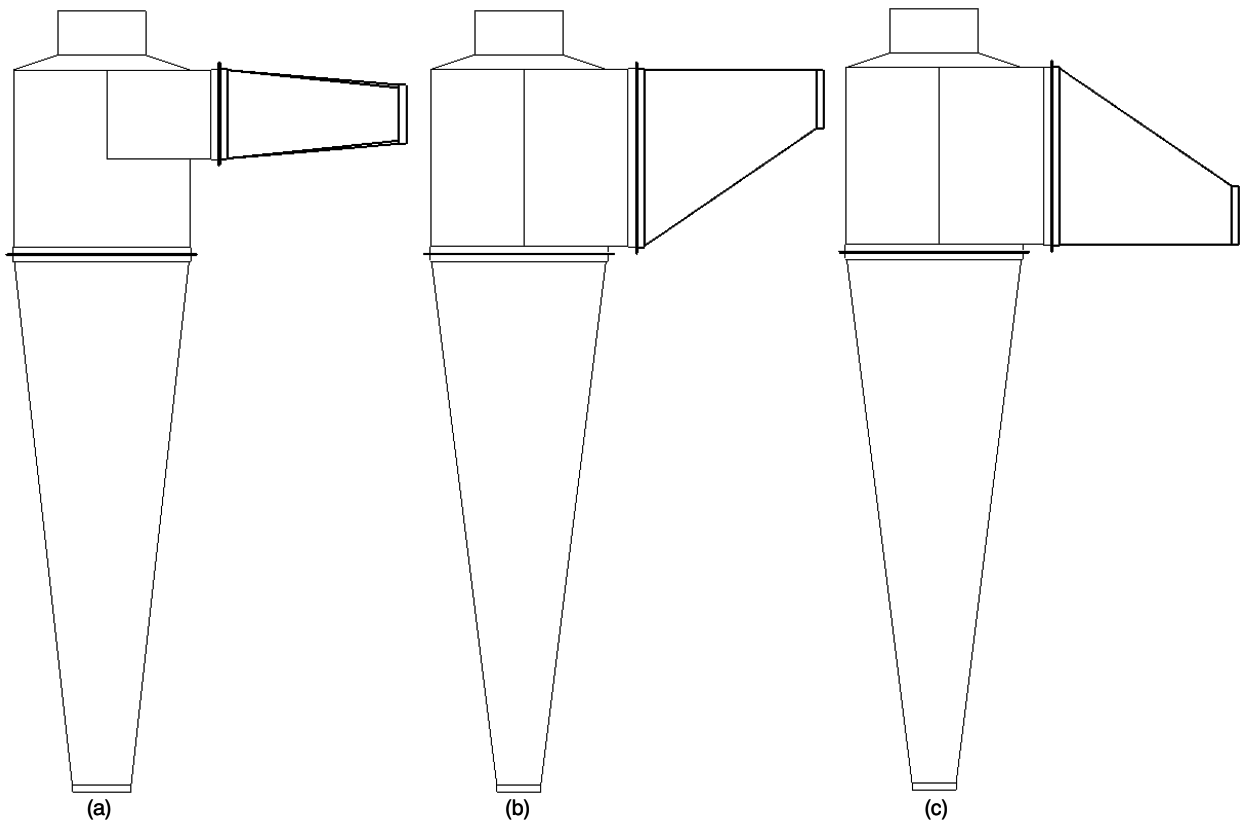


Figure 9. Transitions for (a) recommended 1D3D trash and dust cyclones, (b) original 1D3D dust cyclones, and (c) original 1D3D trash cyclones.

TRASH HANDLING

Cyclones handle both dust and trash. For example, in cotton gins, dust cyclones handle dust, soil particles, and small leaf in the unloading system and handle dust and lint fly in the lint-cleaner and battery-condenser exhausts, and trash cyclones handle larger particles: large leaf, small sticks, and

burrs. Systems that convey significant amounts of trash have higher incidence of choking. Thus, it is strongly recommended that any 1D3D cyclones handling trash be converted to the improved cyclone design with improved inlet and larger trash outlet (fig. 5), especially when components are being replaced.

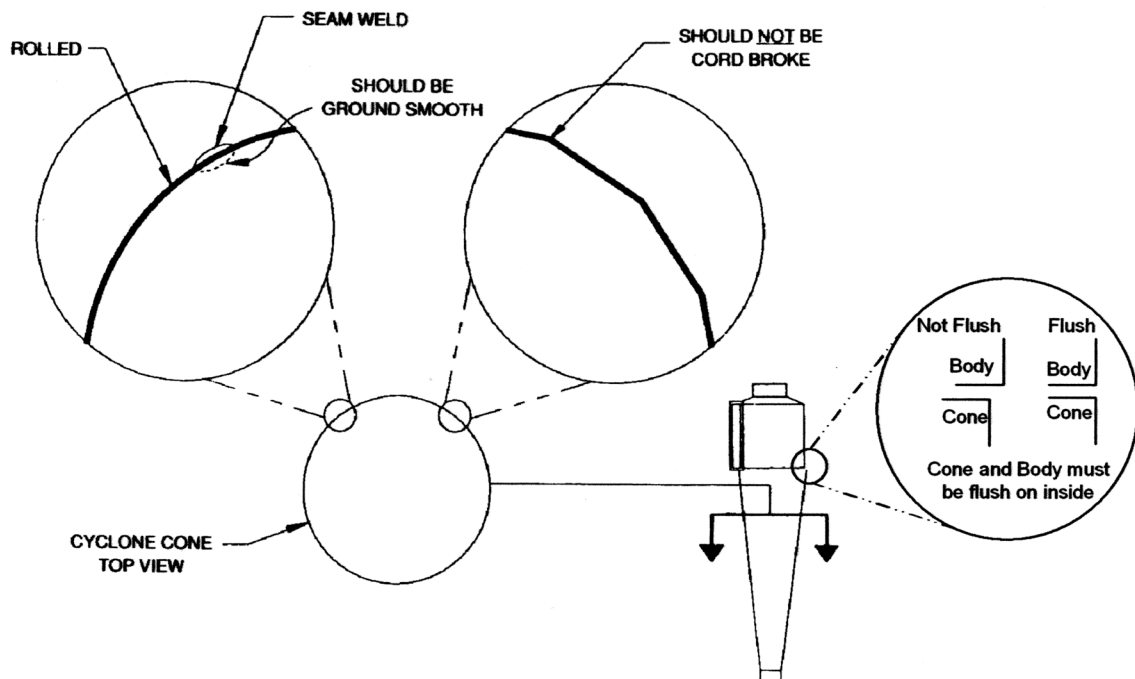


Figure 10. Cyclone construction.



Figure 11. Examples of poor cyclone maintenance (clockwise from top left: dents, joint leaks, wear holes, and stress cracks).

The trash disposal system is an integral part of a cyclone system. The best way to collect cyclone trash and dust is to first place cyclones as close as possible to the source of the particulate. This minimizes the horsepower required to move the trash or dust to the cyclone inlet. It is best to collect the trash and dust exiting the cyclone into a sealed hopper (either directly or with an auger/belt conveyor) which is easily accessible by truck or trailer.

Double handling of dust and trash, collecting dust or trash with one set of cyclones and then picking up this material with a second air stream to be run through a second set of cyclones, should be avoided. Double handling requires more horsepower and can also double the emission rate.

SUMMARY

When used properly, cyclones will collect dust and trash with minimum amounts of particulates exhausted to the atmosphere. In order for cyclones to be effective, they must be properly sized, constructed, and maintained.

When designing a new system or evaluating an existing cyclone design, it is critical to know air velocities and flows in the pipes. Only then can there be assurance that the cyclones are operating as intended.

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APPENDIX 1 - CYCLONE DESIGN

Following is an example, using metric units, of how to design a cyclone system. In this example, numbers in parentheses "()" are not U.S. customary unit equivalents, but are instead similar values representing more typical numbers that might be encountered when working with cyclone systems that were designed using U.S. customary units. For cyclones sizes and measurements based on U.S. customary units the method would be identical, using the correct tables

for U.S. customary units. The primary questions that must be answered prior to designing a cyclone system are:

- Will the cyclones be used for a new facility, new equipment in an existing facility, or as replacements for worn out or undersized existing cyclones?
- Will the cyclones handle trash?

The answers to these questions help determine the number, size, and type of cyclone to be used. For example, the unit cost (dollars per volume of air handled) for one 125-cm (50-in.) 1D3D cyclone may be less than for two 90-cm (36-in.) 1D3D cyclones. However, the 90-cm (36-in.) cyclones are smaller and may fit into an existing cyclone rack better than a 125-cm (50-in.) cyclone. On the other hand, smaller cyclones have smaller trash outlets, increasing the chance for choke-ups, especially with large trash. Cyclone design requires more than only consideration of total air flow.

A common change made to a cyclone system is updating from 2D2D to 1D3D cyclones. In some areas, the 1D3D is required by State Air Pollution Regulatory Agencies when updating or installing new cyclones. Consider the update from 2D2D to 1D3D cyclones for a seed-cotton pre-cleaning/conditioning system of a typical cotton gin rated at 36 bales per hour. The seed-cotton conditioning system consists of a tower dryer, a hot-air inclined cleaner, a stick machine, another tower dryer, and an extractor/feeder. The cyclone system collects trash from the incline, stick machine, and overflow separator. The existing 2D2D system consisted of quadruple 105-cm (42-in.) cyclones on the inclined cleaner, quadruple 100-cm (40-in.) cyclones on the stick machine, and double 120-cm (48-in.) cyclones on the overflow separator. All pipe leading to the existing cyclone system was 60-cm (24-in.) diameter.

To size the 1D3D cyclones, the velocity pressure in the conveying pipes leading to the cyclone bank was measured using the method described previously. Velocity pressures were 600 Pa (2.4-in. H₂O) in the pipe from the inclined cleaner, 450 Pa (1.8-in. H₂O) from the stick machine, and 300 Pa (1.2-in. H₂O) from the overflow separator. Using table 1, the air flow rate in the pipe from the inclined cleaner can be determined by locating the 600 Pa (2.4-in. H₂O) velocity pressure row and moving to the right along the row until it intersects the 60-cm (24-in.) diameter pipe column, which results in 488 m³/min (17,764 ft³/min). Repeating this process for the stick machine with the 450 Pa (1.8-in. H₂O) velocity pressure row and 60-cm (24-in.) diameter pipe column, results in 423 m³/min (15,384 ft³/min) air flow and for the overflow separator with the 300 Pa (1.2-in. H₂O) velocity pressure row and 60-cm (24-in.) diameter pipe column, results in 345 m³/min (12,561 ft³/min) air flow. Next, these air flow rates must be adjusted for temperature and pressure to determine the corrected air flow for conditions different from 21°C and 101.3 kPa (70°F and

29.92-in. Hg). For this example, assume the air temperature is 5°C (40°F) and the facility is located at an elevation of 1200 m (4000 ft) above sea level. Using table 2, the air density correction factor can be determined by locating the row corresponding to 5°C (40°F) and following the row across until it intersects the column corresponding to an elevation of 1200 m (4000 ft), which results in the 1.043 (1.042) correction factor. The corrected air flow rates are then determined by multiplying the air flow rates determined from table 1 by the correction factors. For this example, the corrected air flow rate would be 488 m³/min × 1.043 = 509 m³/min (17,764 ft³/min × 1.042 = 18,510 ft³/min) for the incline cleaner, 423 m³/min × 1.043 = 441 m³/min (15,384 ft³/min × 1.042 = 16,030 ft³/min) for the stick machine, and 345 m³/min × 1.043 = 360 m³/min (12,561 ft³/min × 1.042 = 13,089 ft³/min) for the overflow separator.

Now that the total air flow rates are known, the number of cyclones for each system needs to be determined. In comparing the calculated air flow rates to the rates listed in table 3, the 509 m³/min (18,510 ft³/min) for the incline cleaner falls just below the 530 m³/min (19,000 ft³/min) value listed in the table. To the right of the 530 m³/min (19,000 ft³/min) air flow rate, the table indicates that double 145-cm (58-in.) cyclones or quadruple 105-cm (42-in.) cyclones could be used for the incline cleaners. Knowledge of the existing systems would allow the designer to choose between the two systems. The quadruple 105-cm (42-in.) cyclones are approximately the same size as the existing group and thus may be substituted with little modification to the rack supporting the cyclones. The inlet transition leading from the conveying pipe to quadruple cyclones is more likely to choke than a double or single transition. The tendency in today's agricultural industries is to use fewer, larger cyclones. However, the 205-cm (82-in.) diameter single cyclone that would be needed for 530 m³/min (19,000 ft³/min) air flow rate is beyond what is practical and in use today. Also, a 205-cm (82-in.) cyclone would be quite tall, standing over 9-m (30-ft) tall when installed over an auger, belt, or dust house. Similar selection procedures would show that the stick machine would require a single 190-cm (76-in.), double 135-cm (54-in.), or quadruple 95-cm (38-in.) cyclones and the overflow separator would require a single 170-cm (68-in.), double 120-cm (48-in.), or quadruple 85-cm (34-in.) cyclones. Again, the selection would involve consideration of the existing infrastructure (using similar sized cyclones), the amount of trash handled (using larger cyclones that are less likely to choke when trash is present), and the cost (larger cyclones are lower cost per volume of air handled, but smaller cyclones may require fewer changes to existing racks and ductwork).