TAB Journal

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TESTING & BALANCING HOSPITAL PHARMACY COMPOUNDING ROOMS

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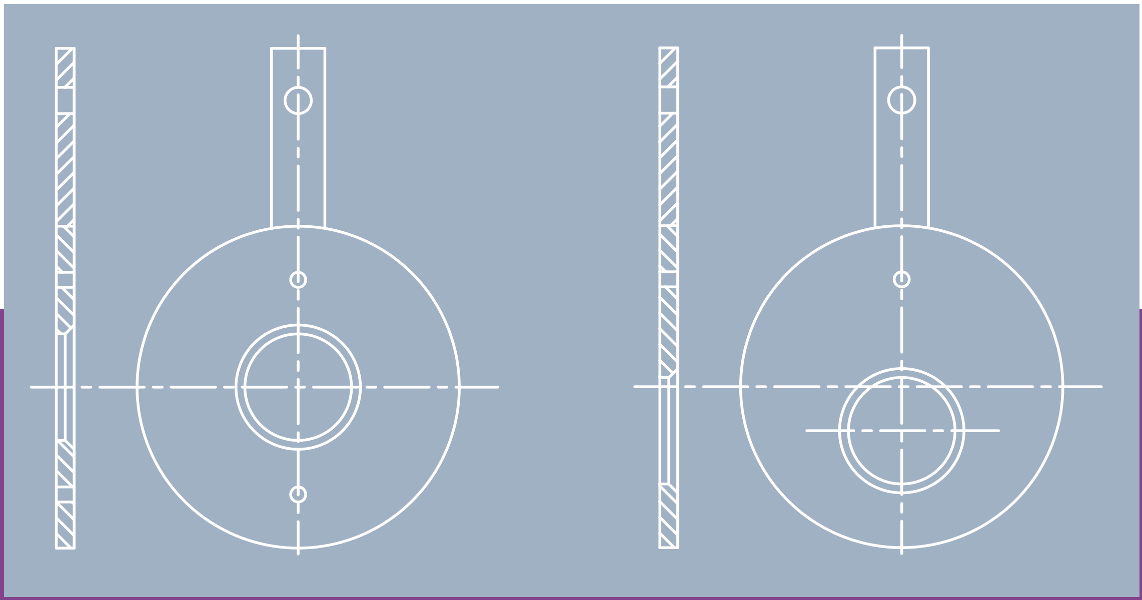

FIELD TESTS OF SQUARE-EDGED ORIFICES

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The temptation to obtain test data as fast as possible, perhaps bending some procedural rules here and there, is always present. An experienced technician will recognize when the bending is too far and results are on the verge of breaking down. Orifice plates provide a method of accurately determining an air flow rate, but if the method is not precisely followed, the results will be wrong. This can lead to many problems if our confidence in orifice plates overrides our awareness that test data are not correlating due to misapplication.

The preferred installation for TAB convenience and accuracy will include an orifice with a manufacturer's tag, which will have the ΔP/flow relationship and duct size noted, and perhaps a flow coefficient. Also necessary are orifice flange taps for static pressure (SP) measurements and sufficient distance upstream and downstream of the orifice for fairly uniform airflow within the duct. With these conditions, the measured ΔP may be referenced to the tagged data per CFMtest = CFMtag x $(\Delta Ptest/\Delta Ptag)^{1/2}$. An air density correction and the manufacturer's flow coefficient may also be applicable.

The difficulty develops when the orifice is not tagged, or is custom made, sized, and installed in the field for a targeted flow rate. Perhaps there is not sufficient straight duct or stable air flow for an accurate velocity traverse, which is a common condition in industrial process exhaust air systems. Any number of reasons may lead us to consult an orifice ΔP/flow chart or use one of the "quick" formulas based on measured ΔP. This is when we may be led astray of accuracy, as we hope to explain with the following analysis.

> "The difficulty develops when the orifice is not tagged, or is custom made, sized, and installed in the field for a targeted flow rate."

In an attempt to determine the extent of inaccuracies in using simplified procedures, formulas, and charts, we built an orifice test duct, as shown in ***Figure 1***. It is installed in one of three duct branches off of a header served by a backward inclined fan. The fan variable frequency drive was used to adjust six flow rates for each of two orifice sizes. Note that this is not, of course, a scientific laboratory test, but it is relevant to conditions available for field testing, with instruments and methods that are common to TAB service, and given an ideal duct installation.

FIGURE 1 NOTES

1. **Sensor 1** SP taps (not SP tips) located on the orifice flange, 1 in. upstream and downstream of orifice plate, per ISO 5167.
2. **Sensor 2** SP taps located 1.0 diameter (8 in.) upstream and 0.5 diameter (4 in.) downstream of orifice plate, per ISO 5167. We have adjusted the downstream location for the actual orifice size relative to duct size, per ***Table 1***.
3. **Sensor 3** SP tips (3 in. long) located 2.5 diameters (20 in.) upstream and 5.5 diameters (44 in.) downstream of orifice plate. These are for "recovery" static pressures to gauge system pressure losses due to the orifice.
4. **Baseline Traverse** with 16 points, 8 equal-area locations along each of two perpendicular axis, 24 in. upstream of orifice plate. A 1/8 in. pitot tube was used. Air flow rate corrected to local air density.
5. **Static Pressure** readings in inches of WC at two-second intervals, and averaged for the two- to three-minute period of the concurrent Baseline Traverse.

The downstream tap location is commonly given as 0.5 of duct diameter. For best accuracy, the location should be at the vena contracta, of which the distance downstream from the orifice will vary depending on the diameter ratio per ***Table 1***.

The two velocity profiles in ***Figure 2*** are at minimum and maximum tested flow rates for reference to laminar flow conditions approaching the orifice plate. The typical traverse extends over a two- to three-minute period, with each velocity sample averaged for a two-second span and recorded. Correction to local air density is provided by the instrument.

The orifice principles are well researched and documented, and we lean on them heavily in the following six suggestions, as applicable to TAB services. ***Table 2*** lists the test data used to confirm the following procedures:

1. Static pressure test locations to obtain an orifice ΔP are specific. Static pressure locations for ΔP sensors 1 and 2 conform to ISO 5167. Static pressure test locations further away from the orifice, such as 2.5 diameters upstream and 8.0 diameters downstream, are referred to as "recovery" taps and are used to gauge system pressure losses due to the orifice, and are not to be referenced for orifice flow calculations.
2. Static pressure readings will be in error if standard SP tips are used. Since they extend into the duct 3 in., the downstream SP tip may be too close, or even within the vena contracta. Also, the SP holes in the tip are an

FIGURE 1: ORIFICE TEST DUCT

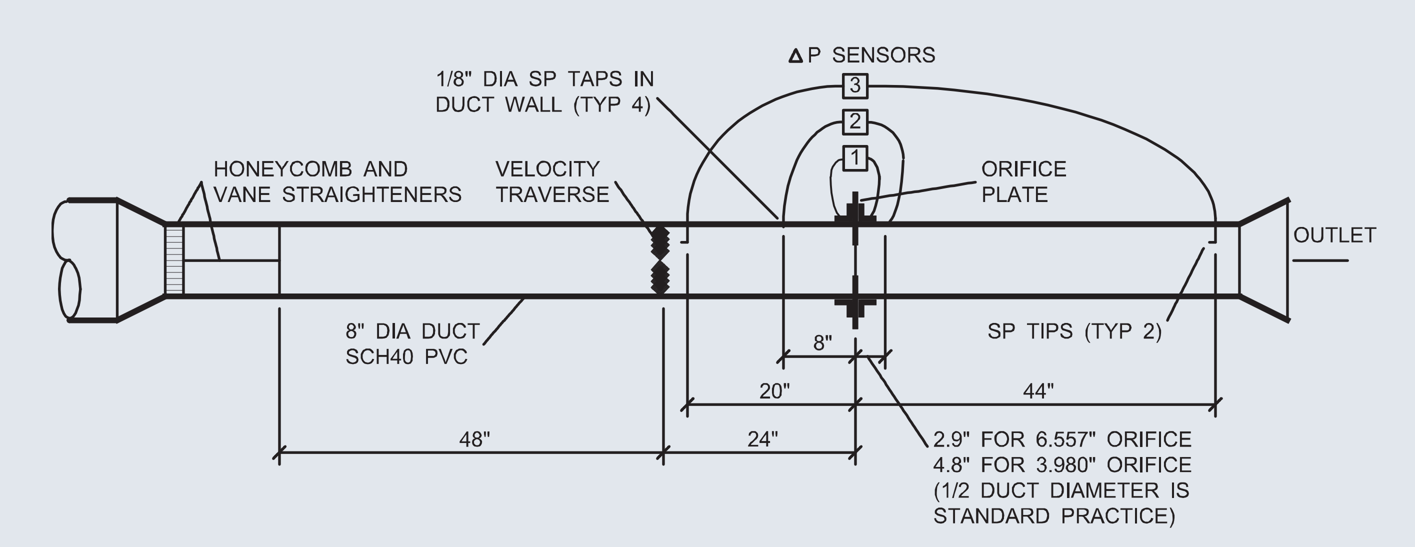


TABLE 1: ADJUSTED LOCATIONS OF DOWN-STREAM TAP PER DIAMETER RATIO

D_2 / D_1	SP Tap Location
0.2	0.74 x D1
0.3	0.71 x D1
0.4	0.66 x D1
0.5	0.60 x D1
0.6	0.53 x D1
0.7	0.45 x D1
0.8	0.36 x D1

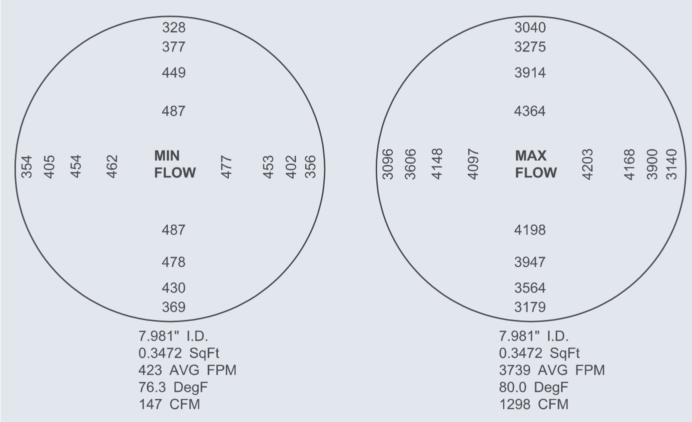
inch upstream of the measured test hole location. Best procedure is to drill a 1/8 in. hole in the duct and press the SP hose against the duct wall. Or, if typical 3/8 in. holes are drilled, cover the hole with electrical or duct tape and punch a SP test hole with the pencil point. The ΔP across the orifice is most accurate with upstream and downstream readings measured simultaneously across the differential meter, with multiple readings averaged. This may read like back-to-school for the basics, but it is important for orifice accuracy.

3. A basic consideration for orifice applications is the Diameter Ratio (β), which is the orifice diameter divided by the duct diameter, D_2/D_1. This is a main component to consider for flow calculations.

TABLE 2: TEST DATA

Orifice Dia "	Baseline Traverse CFM	Orifice ΔP @ Sensor 1			Orifice ΔP @ Sensor 2			Orifice ΔP @ Sensor 3			See Note 5	
		ΔP "WC	Calc'd CFM	Of Trav	ΔP "WC	Calc'd CFM	Of Trav	ΔP "WC	Calc'd CFM	Of Trav	Calc'd CFM	Of Trav
3.980	147	0.3984	144	98%	0.4125	147	100%	0.3044	126	86%	147	100%
3.980	195	0.7049	192	98%	0.7276	195	100%	0.5375	168	86%	195	100%
3.980	231	1.0040	229	99%	1.0384	233	101%	0.7672	200	87%	233	101%
3.980	287	1.5522	285	99%	1.6039	289	101%	1.1879	249	87%	290	101%
3.980	344	2.2191	340	99%	2.2962	346	101%	1.7050	298	87%	346	101%
3.980	374	2.6397	371	99%	2.7338	378	101%	2.0293	325	87%	378	101%
6.557	561	0.4009	541	96%	0.3967	538	96%	0.1827	365	65%	400	71%
6.557	738	0.7066	718	97%	0.6978	713	97%	0.3206	483	66%	530	72%
6.557	875	1.0253	864	99%	1.0091	858	98%	0.4649	582	67%	639	73%
6.557	1084	1.5383	1059	98%	1.5102	1049	97%	0.6954	712	66%	783	72%
6.557	1271	2.2055	1268	100%	2.1595	1255	99%	0.9976	853	67%	937	74%
6.557	1298	2.3127	1298	100%	2.2627	1284	99%	1.0487	874	67%	960	74%

FIGURE 2: VELOCITY PROFILES



4. A simple and common calculation often used for air flow, at standard conditions, through an orifice is CFM = 2610 × Area × $(\Delta P)^{1/2}$, and is accurate only when the β is 0.5. This formula apparently assumes a β of 0.5 and will be in error, perhaps 30%, for other βs since the β has an appreciable effect in the calculation. This common formula may have other uses but is not detailed enough for all orifice applications. It is a simplification of CFM = 4005 × C × A × $(\Delta P)^{1/2}$, for air at standard conditions, where the Flow Coefficient (C) is assumed to be 0.65, but which is still in error for the same β reason.

5. When the β is not 0.5, a new C may be determined. See ***Table 3*** to determine a Discharge Coefficient (C_d) for the actual β. The new C will then be: $C = C_d \times (1 / (1 - \beta^4)^{1/2})$. Then for standard air use CFM = 4005 × C × A × $(\Delta P)^{1/2}$ with the actual C value. (Remember to also factor in the air density correction if necessary.)

The C_d references the cross-sectional area of the vena contracta relative to the area of the orifice opening. ***Table 3*** lists the C_d based on the β and a Reynolds number of 10^4. We have added a third column with a calculated C relative to β and C_d. Note that increases in C are not linear and they become appreciable as the β steps above 0.5, where calculating an accurate C becomes more important. (Flow calculations in ***Table 2*** for the 6.557 in. orifice (β = 0.822) use a C value of 0.8817.)

TABLE 3: DISCHARGE AND FLOW COEFFICIENTS PER DIAMETER RATIO

D_2/D_1 or β	C_d	C
0.2	0.60	0.601
0.4	0.61	0.618
0.5	0.62	0.640
0.6	0.63	0.675
0.7	0.64	0.734
0.8	0.65	0.846

6. We have seen a few charts and tables that offer a flow value from the orifice ΔP but they seem to assume a β of 0.5, again, so are in error at different βs. We also found one chart that establishes a C based on the ratio of the orifice area to the duct area, A2/A1, but it appears to apply a C_d of 0.62 across all area ratios, which will result in an error of a few percent with the larger orifice/duct ratios.

TABLE 2 NOTES

1. Static pressure sensors are shown in ***Figure 1***.

2. Calculated CFM is per: CFM = 4005 × C × A × 1.0314 × $(\Delta P)^{1/2}$, where 4005 is a conversion constant for standard air, C is flow coefficient developed for actual β; A is orifice area; 1.0314 is air density correction; ΔP is orifice differential pressure.

3. Diameter Ratio is based on an 8 in. Sch40 PVC pipe, 7.981 in. inside diameter, and the orifice diameter. Diameter Ratio is 0.499 with the 3.980 in. orifice, and 0.822 with the 6.557 in. orifice.

4. Static pressure tips located at other distances from the orifice (Sensor 3) are for system pressure effect due to the orifice, and are not reliable for orifice flow accuracy, as is evident in this table.

5. Flow calculations in the last columns are per the simple formula CFM = 2610 × Area × $(\Delta P)^{1/2}$ applied to ΔP's in Sensor 1. It is commonly used for orifices and flow charts, and is apparently based on a 0.5 β. Note the large error when applied to the larger orifice, which has a 0.8 β.

CONCLUSION

We have renewed confidence in the use of orifice plates to establish air flow rates from measured differential pressures. Results are surprisingly close within a few percent when accurate instruments are used and proper methods and formulas are applied. The orifice β is a first consideration. If differential static pressures are not obtained at the proper locations with proper procedures, or if quick formulas and convenient pressure/flow charts are used when the β of the orifice/duct is not at 0.5, results will be in error as much as 30%.

TEST AND INSTRUMENTATION NOTE

Tests were conducted in the Evergreen Telemetry calibration facility. Static pressures, temperature, and flow velocities were measured with Evergreen Telemetry wireless differential pressure modules and Wrist Reporters™ for data logging. All pressure modules were new, with on-site NIST traceable calibration. Assistance was provided by Pete Secor of Evergreen Telemetry and Michael Bloom of Arizona Air Balance Company.