CALIBRATION OF METHOD 6 METERING SYSTEMS
USING CRITICAL ORIFICES

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INTRODUCTION

Section 7.2 of Method 6 allows the use of critical orifices for volume and sampling rate measurements. Basically, the procedure requires a calibration with a bubble flow meter before and after each test run. For the volume measurement to be valid, the before and after flow rates must agree to within ±5.0%.

Method 6 currently does not specifically allow the use of critical orifices as calibration standards for its metering system as does Method 5. This paper presents laboratory data that justifies the use of critical orifices as calibration standards for Method 6 metering systems.

ORIFICE METER CALIBRATION PROCEDURE

The calibration procedure uses the Method 6 metering system, modified by installing a vacuum gauge before the needle valve. A bubble meter with a temperature gauge is attached to the outlet of the metering system because any attachments to the inlet of the orifice affects its calibration. The following procedure was used to select and calibrate the critical orifices.

1. Remove or bypass the drying tube from the metering system. Leak-check pump and post-pump components. The leakage rates must be zero.
2. Insert the critical orifice into the inlet of the meterbox. Connect a 500-cc bubble meter and temperature gauge to the outlet of the meterbox. Record the ambient temperature.
3. Turn on the pump and open the needle valve until the vacuum reaches 18 in. Hg. Leak-check the system from the inlet of the critical orifice as follows. Start a bubble, then plug the inlet to the orifice. The bubble must remain stationary for at least 10 seconds.
4. Using a stopwatch, measure the time it takes for a bubble to travel the distance. Record the bubble meter and ambient temperatures. Run at least triplicate runs until the difference from the average is $\leq$0.6 sec for 0.5 Lpm; $\leq$0.3 sec for 1.0 Lpm; and $\leq$0.15 for 2.0 Lpm. Alternatively, the K' factor should all be within ±1.0% from the average.
5. Calculate the K' factor for each run, and then calculate the average for the triplicate (or more) runs.

$$K' = 17.65 \frac{V_{sb} \sqrt{T_{amb}}}{T_{sb}\ \theta}$$

where:

V_{sb} = Volume of soap bubble meter, L
T_{amb} = Absolute ambient temperature, °F
T_{sb} = Absolute soap bubble meter temperature, °F
θ = Time, min

METERING SYSTEM CALIBRATION PROCEDURE

The following procedure was used for the initial and post-test calibration procedure:

1. Remove the drying tube. Insert the critical orifice to the inlet of the meterbox. Start the pump and set the vacuum to 18 in. Hg. Leak-check the system from the inlet of the critical orifice. The leakage rate must be zero.
2. Using a stopwatch, start the time when the DGM dial passes the zero reference. Pass at least 5 revolutions of gas through the meterbox dry gas meter (DGM). Stop the time when the DGM dial passes the zero reference after 5 revolutions.
3. Record the information requested in Figure 2. Run duplicate runs until the difference from the average is $\leq$0.6 sec for 0.5 Lpm; $\leq$0.3 sec for 1.0 Lpm; and $\leq$0.15 for 2.0 Lpm.
4. Calculate Y_i, the DGM calibration factor for each run; average the results. Each Y_i must be ±2% from the average.

$$Y_i = \frac{K' \, T_d \, \theta}{17.65 \, V_d \sqrt{T_{amb}}}$$

where:

T_d = average DGM temperature.
V_d = DGM volume.

5. For post-test calibrations, repeat steps 1 through 4, except do not conduct the leak-check and three DGM revolutions may be used rather than five. The initial and post-test DGM calibration factor must agree to within ±5.0%.

LABORATORY EVALUATION AND RESULTS

Selection of Critical Orifices

According to Section 7.2.2 of Method 6, the suitability and appropriate operating vacuum are determined by slowly increasing the vacuum while observing a rotameter reading. Because of the gradual change in the flow rate, it was difficult to gauge when a critical vacuum was reached by observing the rotameter. Therefore, the bubble meter was used. The results are shown in Table 1 and graphically in Figure 1.

According to Figure 1, the critical orifice never reached a constant reading. Because the changes were relatively small beyond 17 in. Hg vacuum, it was arbitrarily decided to run all calibrations at 18.0 in. Hg.

Table 2 shows K' calibration factors for various orifices. For the 2 Lpm orifices, the maximum vacuum attainable was slightly over 14 in. Hg. The K' factors were determined for these 2 Lpm orifices at 14 and 13 in. Hg vacuum to ascertain the sensitivity of the operating vacuum. Differences from the 14 in. Hg were 0.77% and 1.42%, which were well within the allowed accuracy of ±2.0%. Therefore, it was concluded that these orifices (although they could not be classified as true critical orifices) could be used for meterbox calibrations as long as the needles were calibrated and operated at the same vacuum readings.

Initial and Post-test Calibrations

Table 3 shows the results of the critical orifice calibrations and the initial (pre-test) and post-test calibrations of the Method 6 metering system. The table also shows the effect of the number of revolutions of the DGM versus accuracy. The data show that at least two revolutions are needed to obtain ±3.0% accuracy. The current criteria of five revolutions for the initial calibration and three revolutions for the post-test calibration check are adequate.

CONCLUSIONS

Hypodermic needles used as orifices have been shown to be highly reproducible and accurate for the determination of flow rates. Thus, these needles may be used as orifices for the calibration of Method 6 type of metering systems, provided that they are calibrated and operated (for meterbox calibrations) at the same outlet vacuums. Five revolutions of the DGM are needed to obtain the desired ±2.0% accuracy, and two or three revolutions for post-test calibrations are adequate to detect ±5.0% accuracy changes.

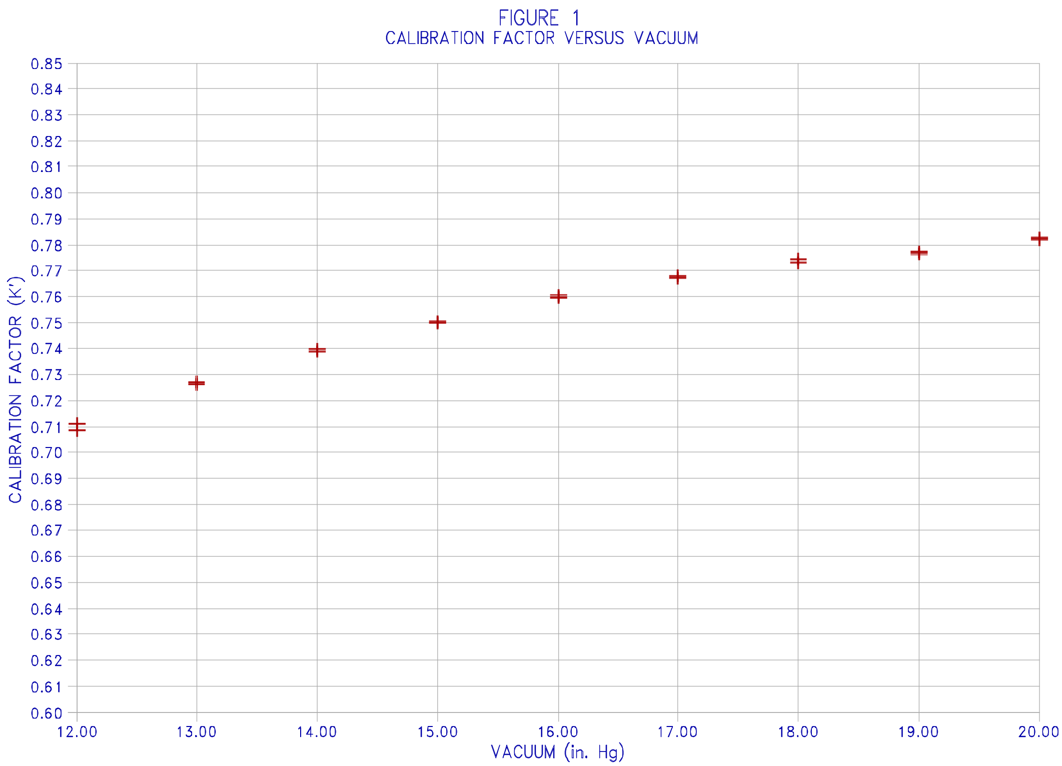
FIGURE 1
CALIBRATION FACTOR VERSUS VACUUM
CALIBRATION FACTOR (K')
0.85
0.84
0.83
0.82
0.81
0.80
0.79
0.78
0.77
0.76
0.75
0.74
0.73
0.72
0.71
0.70
0.69
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.60
12.00
13.00
14.00
15.00
16.00
17.00
18.00
19.00
20.00
VACUUM (in. Hg)

TABLE 1

STANDARD CRITICAL ORIFICE CALIBRATION

Meter Box ID# V-11 Date: 1/23-25/96 Bubble Meter Volume = 0.500 L

Metering System Leak Check OK Orifice Inlet Leak Check OK

	Tamb F	Tbub F	Time sec	K'	%Diff
1/23/96	72.5	72.5	29.70	0.7726	0.06
	72.5	72.5	29.67	0.7734	0.16
1/24/96	73.0	73.0	29.71	0.7720	-0.02
	73.0	73.0	29.68	0.7727	0.08
	73.0	73.0	29.78	0.7702	-0.26
	73.0	73.0	29.74	0.7712	-0.13
	73.0	73.0	29.64	0.7738	0.21
	73.0	73.0	29.73	0.7714	-0.09
			AVG	0.7722	
After cal	73.0	73.0	29.91	0.7668	-0.69
	73.0	73.0	29.81	0.7694	-0.36
	73.0	73.0	29.84	0.7686	-0.46
	73.0	73.0	29.84	0.7686	-0.46
	73.0	73.0	29.90	0.7671	-0.66
			AVG	0.7681	-0.53

%Diff is from 0.7722

EFFECT OF OUTLET VACUUM

1/25/95 in. Hg	Tamb F	Tbub F	Time sec	K'		
						0.71
20	68.8	68.8	29.45	0.7819	0.7823	
20	68.8	68.8	29.42	0.7827		0.39
19	68.8	68.8	29.63	0.7771	0.7767	
19	68.8	68.8	29.66	0.7763		0.79
18	68.8	68.8	29.73	0.7745	0.7737	
18	68.8	68.8	29.79	0.7729		1.01
17	68.8	68.8	30.01	0.7673	0.7677	
17	68.8	68.8	29.98	0.7680		1.32
16	68.4	68.4	30.30	0.7602	0.7600	
16	68.4	68.4	30.32	0.7597		1.43
15	68.4	68.4	30.72	0.7498	0.7501	
15	68.4	68.4	30.70	0.7503		1.74
14	68.4	68.4	31.17	0.7390	0.7395	
14	68.4	68.4	31.13	0.7400		2.41
13	69.0	69.0	31.69	0.7265	0.7268	
13	69.0	69.0	31.66	0.7272		
12	68.6	68.6	32.39	0.7110	0.7097	
12	68.6	68.6	32.51	0.7084		

Initial setup did not have a bubble meter thermometer.

Ambient and bubble meter temperatures were assumed to be same.

TABLE 2

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STANDARD CRITICAL ORIFICE CALIBRATION

Meter Box ID# V-11 Date: 2/29/96 Bubble Meter Volume = 0.500 L

Metering System Leak Check OK? (=0?): Yes Cal by: R. Shigehara

	Tamb F	Tbub F	Time sec	K'	%Diff
Orifice ID# 1	70	70.2	29.88	0.7695	0.19
18" Hg	70	70.2	30.15	0.7626	-0.71
1 Lpm	70	70.2	29.88	0.7695	0.19
	70	70.2	29.78	0.7720	0.53
Leak Chk OK	71	71.0	30.13	0.7626	-0.70
	71	71.2	29.75	0.7721	0.53
	71	71.4	29.91	0.7677	-0.04
			AVG	0.7680	
Orifice ID# 2	72	72.0	31.53	0.7281	0.55
18" Hg	72	72.0	31.66	0.7251	0.14
1 Lpm	72	72.4	31.65	0.7248	0.09
	72	72.6	31.66	0.7243	0.02
Leak Chk OK	72	72.8	31.91	0.7183	-0.80
			AVG	0.7241	
Orifice ID# 3	74	74.0	64.03	0.3579	0.11
18" Hg	73	73.2	63.62	0.3604	0.81
0.5 Lpm	72	72.2	64.09	0.3581	0.16
	72	72.2	64.09	0.3581	0.16
Leak Chk OK	72	72.0	64.56	0.3556	-0.53
	71	71.4	64.19	0.3577	0.06
	71	71.0	64.78	0.3547	-0.77
			AVG	0.3575	
Orifice ID# 4	72	71.8	29.35	0.7825	-0.24
18" Hg	72	71.8	29.40	0.7811	-0.41
1 Lpm	72	72.4	29.18	0.7861	0.23
	72	72.4	29.03	0.7902	0.75
Leak Chk OK	72	72.4	29.31	0.7827	-0.21
	73	73.0	29.28	0.7833	-0.13
			AVG	0.7843	
Orifice ID# 5	71	71.0	54.88	0.4187	-0.92
18" Hg	71	71.4	54.32	0.4227	0.02
0.5 Lpm	72	72.0	54.56	0.4208	-0.44
	73	73.6	54.10	0.4235	0.20
Leak Chk OK	73	73.4	54.59	0.4198	-0.66
	74	74.2	53.84	0.4254	0.67
	75	74.6	54.09	0.4235	0.22
			AVG	0.4226	

QA/QC Check: Completeness, Legibility, Accuracy, Specifications, Reasonableness are OK

Checked by: (Lab Supervisor/Date) _________________________

TABLE 2 (Continued)

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STANDARD CRITICAL ORIFICE CALIBRATION

Meter Box ID# V-11 Date: 2/29/96 Bubble Meter Volume = 0.500 L

Metering System Leak Check OK? (=0?): Yes Cal by: R. Shigehara

	Tamb	Tbub	Time	K'	%Diff
Orifice ID# 6	72	71.6	16.22	1.4164	-0.64
14" Hg	72	71.8	16.15	1.4220	-0.25
2 Lpm	72	72.0	16.09	1.4268	0.08
	72	72.0	15.97	1.4375	0.84
Leak Chk OK	72	72.2	16.13	1.4227	-0.20
	72	72.2	16.01	1.4334	0.55
	72	72.0	16.12	1.4241	-0.10
	72	72.0	16.13	1.4232	-0.16
	72	72.0	16.12	1.4241	-0.10
			AVG	1.4256	
Orifice ID# 6	72	72.2	16.38	1.4010	0.00
13" Hg	72	72.2	16.34	1.4044	0.24
2 Lpm	72	72.2	16.44	1.3959	-0.37
	72	72.2	16.38	1.4010	0.00
Leak Chk OK	72	71.8	16.37	1.4029	0.13
			AVG	1.4010	
Orifice ID# 7	72	70.6	15.25	1.5093	-0.17
14" Hg	72	71.6	15.16	1.5154	0.23
2 Lpm	72	70.8	15.25	1.5088	-0.21
	72	70.8	15.21	1.5127	0.05
Leak Chk OK	72	70.8	15.16	1.5177	0.38
	72	70.6	15.25	1.5093	-0.17
	72	70.8	15.28	1.5058	-0.41
	72	70.6	15.19	1.5153	0.22
	72	70.6	15.16	1.5183	0.42
	72	70.6	15.28	1.5064	-0.37
	72	70.6	15.19	1.5153	0.22
	72	70.6	15.25	1.5093	-0.17
			AVG	1.5120	
Orifice ID# 7	71	70.4	15.47	1.4870	0.89
13" Hg	71	70.4	15.47	1.4870	0.89
2 Lpm	71	70.6	15.72	1.4628	-0.76
	71	70.4	15.59	1.4756	0.11
Leak Chk OK	71	70.4	15.69	1.4662	-0.53
	71	70.4	15.63	1.4718	-0.15
	71	70.2	15.57	1.4780	0.28
	71	70.2	15.75	1.4611	-0.87
	71	70.2	15.59	1.4761	0.15
	71	70.2	15.66	1.4695	-0.30
	71	70.2	15.59	1.4761	0.15
	71	70.2	15.59	1.4761	0.15
			AVG	1.4740	

QA/QC Check: Completeness, Legibility, Accuracy, Specifications, Reasonableness are OK

Checked by: (Lab Supervisor/Date)

TABLE 3

NONISOKINETIC METERING SYSTEM CALIBRATION

Meter Box ID# V-11

Date: 1/24/96

Metering System Leak Check OK

Orifice Inlet Leak Check OK

	DGM T1	T2	min	sec	Y	%Diff
1/24/96						
Pre	71.6	72.0	5	3.36	1.0190	
	72.0	72.8	5	5.13	1.0261	
	72.8	73.6	5	2.76	1.0197	1.0216
Post	73.8	74.2	3	5.34	1.0419	
	74.2	74.6	2	55.34	0.9864	
	74.8	75.2	3	0.91	1.0189	1.0158

EFFECT OF NUMBER OF REVOLUTIONS

No. Rev.	T1	T2	min	sec	Y	%Diff
1	75.8	75.8	0	54.36	0.9199	-9.96
2	75.8	75.8	2	1.49	1.0279	0.62
3	75.8	76.2	2	55.64	0.9911	-2.99
4	76.2	76.0	3	58.05	1.0076	-1.37
5	76.0	76.2	5	3.74	1.0285	0.68
1	76.2	76.2	0	53.62	0.9080	-11.12
2	76.2	76.2	1	58.9	1.0068	-1.45
3	76.2	76.2	2	58.75	1.0090	-1.23
4	76.2	76.2	3	54.15	0.9913	-2.97
5	76.2	76.2	5	0.40	1.0174	-0.41
1	76.2	76.2	0	54.00	0.9145	-10.49
2	76.2	76.4	2	0.83	1.0233	0.16
3	76.4	76.4	3	6.21	1.0515	2.93
4	76.4	76.4	4	0.05	1.0167	-0.48
5	76.4	76.4	5	4.89	1.0330	1.12