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ORIGINAL ARTICLE

Evaluation of the Jarless Method for Cyclone Calibration in Occupational Air Sampling

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ABSTRACT

The jarless cyclone calibration method is an appealing approach because it removes the need for calibration adapters and eliminates potential sources of error that result from poor or inconsistent seals in calibration adapters or calibration jar lids. The aim of this study was to perform a detailed review of the jarless calibration method by (1) examining the rationale behind the initial pressure drop range specified by the method and (2) evaluating the accuracy of the method in contrast to flow rate measurements in a well-controlled, jar protocol. Four types of respirable cyclones and two filter brands with samples from three separate production lots were considered as components of the sampling trains under consideration. Volumetric flow rate and pressure drop were measured under controlled conditions in a cylindrical jar designed for these determinations. The initial challenge pressure range evaluated in this study was modified based on cyclone type. The measured pressure drop fell within the modified range for all configurations considered, indicating the modified ranges were appropriate. The accuracy of the jarless method was then evaluated by comparing measured volumetric flow rates using different calibration methods for various cyclone, filter brand, and filter lot combination. The jarless method provided accurate calibration results utilizing the modified initial pressure drop ranges utilized in this study. Therefore, it is recommended the initial pressure drop range specified by the jarless method be modified to account for differences among cyclone types.

KEYWORDS: *Pressure Drop, Respirable Fraction, Aerosol Sampling*

INTRODUCTION

Occupational exposure to inhaled aerosols can result in adverse health effects ranging from mild irritation to chronic and terminal illness [1]. Aerosols suspended in air range in size from 0.001 to 100 µm in diameter [2]. Particle size governs aerosol transport mechanisms and the site of deposition in the respiratory tract [1-2]. Scientific bodies such as the American Conference of Governmental Industrial Hygienist (ACGIH), the International Organization for Standardization (ISO), and the Committee European de Normalization (CEN) have published harmonized criteria that assigns probability estimates, as a function of aerodynamic particle size, to the deposition of inhaled aerosols in a particular region of the respiratory tract [3-5].

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Size selective sampling techniques are available to measure aerosols defined by three progressively smaller categories: inhalable, thoracic, and respirable fractions. The respirable fraction, or the fraction of particles that penetrate the gas exchange region of the lung, is quantitatively described by a cumulative log-normal distribution with a median aerodynamic diameter of 4.25 µm and a geometric standard deviation (GSD) of 1.5 [3-5].

A sampling strategy to measure the respirable fraction is required when an aerosol targets the gas-exchange region of the lung. The ACGIH/ISO/CEN size-selective sampling criteria stipulates a sampler collection efficiency that matches a log-normal distribution curve with a 50% (median) cut-point of 4.0 µm [2]. Cyclones and impactors are commonly used to sample the respirable fraction; the former being the most used approach. Cyclones rely on centrifugal force to separate particles according to aerodynamic diameter [2]. The particle size-selective efficiency of a cyclone is a complex function of sampler geometry, sampling flow rate, sampler orientation, and air current patterns external to the sampler [1].

Historically, the most widely used cyclone in the United States was the 10-mm Dorr-Oliver nylon cyclone, designed to meet the 1971 Occupational Safety and Health Administration (OSHA) respirable dust collection efficiency curve (50% cut-point of 3.5 µm) when operated at a flow rate of 1.7 liters per minute (lpm) [2]. The dynamics of the Dorr-Oliver nylon cyclone have been well tested with silica and shown to exhibit orientation bias and accumulation of static charge [2-6]. In the final rule for respirable crystalline silica, OSHA acknowledged that the 1971 specifications for respirable dust samplers were obsolete and stipulated that respirable crystalline silica sampling be performed using a device that meets ISO 7708:1995 Air Quality-Particle Size Fraction Definitions for Health-Related Sampling" [7]. However, as of this writing, the Dorr-Oliver nylon cyclone remains commercially available [8].

Respirable Dust Samplers: Current Trends:

Various cyclones designed to meet the ACGIH/ISO/CEN respirable sampler efficiency criteria (50% cut-point of 4.0 µm) and address limitations of the Dorr-Oliver nylon cyclone are available, each with specified operating parameters. The aluminum cyclone (SKC Inc., Eighty Four, PA) meets the criteria when operated at a flow rate of 2.5 lpm [9]. The aluminum cyclone was specified in the National Institute for Occupational Safety and Health (NIOSH) Manual of Analytical Methods (NMAM) 7500 for silica and 0600 for respirable particulates [10-11]. The metal construction eliminates electrostatic concerns and the open-face orientation enhances collection [8]. The GS-3 cyclone (SKC Inc., Eighty Four, PA), developed at West Virginia University, meets the criteria when operated at a flow rate of 2.75 lpm [6]. The GS-3 is constructed of conductive plastic which eliminates concerns associated with static electricity and spark hazards and is safe for use in mining applications. Three inlet slits overcome orientation bias and open-face orientation enhances collection [6]. The Zefon® 10-mm conductive nylon cyclone (Zefon International, St. Petersburg, FL) meets the criteria when operated at a flow rate of 1.7 lpm [12]. The Zefon® was designed to precisely match the internal workings of the Dorr-Oliver 10-mm nylon cyclone while providing the added benefit of being electrically conductive [12]. It meets the NIOSH requirement for 10-mm nylon cyclones as specified in the NMAM 0600 for respirable particulates and NMAM 7500, 7501, 7601, and 7602 for silica dust [10-13-15].

Achieving Performance, Flow Rate Assurance:

The flow rate specified by the cyclone manufacturer is a critical parameter based on sampler geometry to provide optimum size separation according to the ACGIH/ISO/CEN respirable collection efficiency criteria [2]. Thus, reliable air monitoring requires calibration of the sampling train to verify the specified flow rate is achieved and maintained over the sampling collection period.

A primary standard calibration device measures the flow rate of a known volume of air with an accuracy of ±1% [2-16]. Electronic wet (soap bubble) and electronic dry (low friction piston) flow meters are commonly used as primary calibration devices [17]. Fittings are needed to connect the flow rate meter to the sampling device of choice during the calibration procedure. Concerning these fittings, the aluminum cyclone is equipped with a commercially available aluminum calibration adaptor (SKC Inc., Eighty Four, PA) which fits over the cyclone and allows direct connection to the flow rate calibrator. However, the Dorr-Oliver nylon cyclone, GS-3 cyclone, and Zefon® cyclone are not equipped with such a calibration adaptor. Due to their inlet designs, these cyclones have traditionally been calibrated using the Jar method [2-11]. Per the Jar method, the cyclone assembly (cyclone + cassette) is placed inside an airtight calibration jar equipped with inlet and outlet ports. The jar in this case serves as a universal calibration adapter.

The Jar method is no longer recommended by OSHA due to technical issues such as leakage of the jar lid [17]. Further, calibration jars are not endorsed when calibrating cyclones using electronic dry-piston flow meters [18]. In an application note provided by MesaLabs (Mesa Labs, Butler, NJ), the use of calibration jars with dry-piston flow meters is not recommended due to measurement error associated with undetectable air leaks and because, calibration jars insert large gas volume, or dead inventory volume, between the filtration element and the standard, introducing further measurement error" [18].

To overcome the limitations of the jar calibration method, the OSHA Technical Manual (OTM) provides instructions for pump calibration via a Jarless Cyclone Calibration Method [16]. The Jarless method was also published in the appendix of NMAM 0600 [11]. According to the OTM, "the purpose of the procedure is to determine whether the sampling pump will be able to maintain the required flow rate as the drop in static pressure across the sampler grows due to particulates loading up on the filter." Per the OTM, the typical pressure drop across a clean 5-µm filter is 2 inches of water pressure. The cyclone assembly was expected to attribute an additional pressure drop of approximately 0.25 inches. The method states that as the filter is loaded, pressure drop reaches values as high as 20 inches of water pressure [17]. The step-by-step procedure for the Jarless method as published in the NMAM 0600 appendix has been reproduced in Figure 1.

This procedure may be used in the field to calibrate an air sampling pump and a cyclone assembly without using the one-liter "calibration jar".

1. Connect the pump to a pressure gauge or water manometer and a light load (adjustable valve or 5-µm filter) equal to 2" to 5" H_2O with a "TEE" connector and flexible tubing. Connect other end of valve to an electronic bubble meter or standard bubble tube with flexible tubing
   NOTE: A light load can be a 5-µm filter and/or an adjustable valve. A heavy load can be several 0.8-µm filters and/or adjustable valve.
2. Adjust the pump to 1.7 L/min, as indicated on the bubble meter/tube, under the light load conditions (2" to 5" H_2O) as indicated on the pressure gauge or manometer.
3. Increase the load until the pressure gauge or water manometer indicates between 25" and 35" H_2O. Check the flow rate of the pump again. The flow rate should remain at 1.7 L/min ± 5%.
4. Replace the pressure gauge or water manometer and the electronic bubble meter or standard bubble tube with the cyclone having a clean filter installed (Fig. 2.2). If the loading caused by the cyclone assembly is between 2" and 5" H_2O, the calibration is complete and the pump and cyclone are ready for sampling.

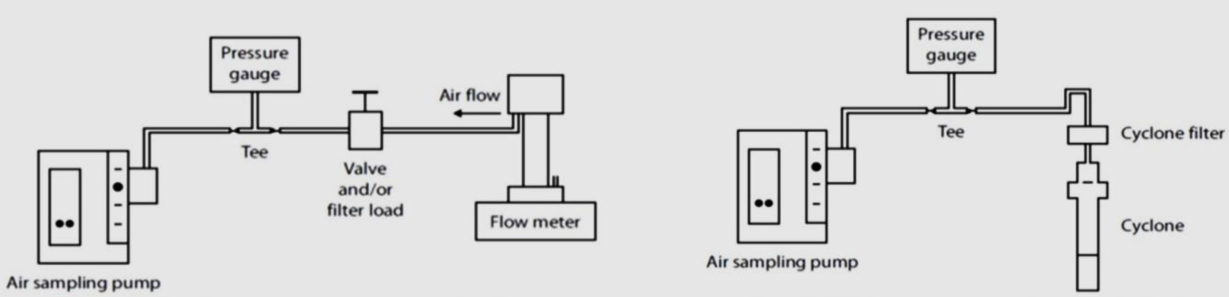

Fig 1. Jarless method for Calibration of Cyclone Assemblies

The OSHA Jarless Method, Procedural Voids:

The Jarless method relies on mechanical means to create a pressure drop at two extreme settings. The low pressure drop setting, that is equivalent to that of a clean sampler, was used to set the flow rate at the specified value in the air sampling pump. The high pressure drop setting, that is equivalent to that of a fully-loaded sampler, was used to verify if the initial flow rate remains relatively unchanged (less than 5% of change) at challenging pressure conditions. The Jarless, or pressure-drop method, has multiple advantages. It removes a need for calibration adapters, it does not require a reserved additional sampler for calibration, and most importantly, it eliminates potential sources of error that result from a poor or inconsistent seal of calibration adapters or calibration jar lids [19].

The Jarless calibration method is an attractive approach due to the above listed advantages and the simplicity of its protocol. However, this protocol includes some voids that have not been yet addressed. The pressure end points (equivalent to a clean and fully-loaded sampler) have been chosen without referencing studies that justify their point setting. The lower end pressure drop seems to apply to a cyclone with a recommended flow rate of 1.7 lpm and a design like the traditional Dorr Oliver model. However, this low-end pressure drop recommendation was flow-rate and design dependent and may require variable values, each matching the type of sampler selected.

Furthermore, the high-end pressure drop could be greater than the 20 inches of water gage for samplers requiring greater than 1.7 lpm of operational flow rate. The current study was focused on a detailed review of the Jarless calibration method and was accomplished in two parts. Part one examined the rationale behind the initial pressure drop range (2 to 5 inches of water gauge) specified by the jarless method. Part two evaluated the accuracy of the Jarless method in contrast to flow rate measurements in a well-controlled, jar protocol.

METHODS

Part I:

The jarless method specifies an initial pressure drop of 2-5 inches of water gauge (in. w.g.). However, results from a previous study (see Table 1) demonstrated that the pressure drop created by a clean sampler at the volumetric flow rate specified by the manufacture varies by cyclone type and filter brand [20]. Therefore, the initial pressure drop utilized in the current study was modified based on cyclone type. Since the choice of filter brand was more random than the cyclone type, the range of pressure drop for the cyclone filter combination was selected based on the minimum and maximum pressure drop observed (regardless of filter brand) rounded to the nearest whole number [20]. Initial pressure drop ranges utilized, each equivalent to a given sampling train, has been provided in Table 2.

Table 1. Median sampler pressure drop at flow rates specified by cyclone manufacturers [20]

Cyclone Type	Filter Brand	Minimum ΔP [a]	Median ΔP (95% CI)	Maximum ΔP
Nylon	SKC	1.165	1.634 (1.534, 1.759)	1.801
	Zefon	0.751	1.447 (0.858, 1.809)	1.920
Zefon	SKC	0.858	1.730 (1.682, 1.809)	1.969
	Zefon	1.694	2.092 (1.809, 2.181)	2.210
GS-3	SKC	1.292	1.489 (1.409, 1.947)	2.651
	Zefon	1.410	3.094 (2.509, 3.304)	3.502
Aluminum	SKC	1.404	2.480 (2.367, 2.524)	2.707
	Zefon	1.147	2.625 (2.250, 2.805)	2.853

[a] Pressure drop (in. w.g)

Table 2. Expected sampler pressure drop at flow rate specified by the cyclone manufacture

Cyclone type	Specified flow rate [a]	ΔP [b] Range
Nylon	1.70	1.0 – 2.0
Zefon	1.70	1.0 – 2.0
GS-3	2.75	1.0 – 4.0
Aluminum	2.50	1.0 – 3.0

[a] Standard volumetric flow rate in liters per minute (lpm)
[b] Pressure drop (in. w.g)

Commercial sampler and filter media selection:

Table 3 presents a matrix of the sampling train configurations considered to verify actual pressure drop and actual standard volumetric flow rate, SVFR, after the sampling pump was submitted to calibration following the jarless protocol. These configurations included four respirable dust cyclones commonly used for air sampling in industrial hygiene and two commercial brands of 37-mm, 5-µm pore size, polyvinyl chloride (PVC) filters with samples from three separate production lots. An AirChek TOUCH sampling pump (SKC Inc., Eighty Four, PA, USA) was used in all the trials. The sampler pressure drop (cyclone + filter) at the volumetric flow rate specified by the manufacturer was measured under multiple combinations of sampler type and commercial filter brand, including manufacturing lot. Pressure drop was measured using a digital manometer (Model 475-00-FM Dwyer Instruments, Michigan City, IN, USA).

Table 3. Sampling train configurations for Part I

Cyclone Type	**PVC filter, 5.0-µm, 37-mm**	
Aluminum cyclone *(n=1)* 	Brand: SKC Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*	Brand: Zefon Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*
10-mm Dorr-Oliver nylon cyclone *(n=1)* 	Brand: SKC Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*	Brand: Zefon Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*
Zefon® 10mm conductive nylon cyclone *(n=1)* 	Brand: SKC Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*	Brand: Zefon Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*
GS-3 cyclone *(n=1)* 	Brand: SKC Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*	Brand: Zefon Lot 1 *(n=3)* Lot 2 *(n=3)* Lot 3 *(n=3)*

Standard volumetric flow rate (SVFR, actual volumetric flow rate corrected to standard conditions of temperature and pressure) expressed at 760 mm of Hg (101.3 kPa) and 21.1 C was measured using a mass flowmeter (Model 4140 TSI Inc. Shoreview, MN, USA).

Reference Calibration Jar:

An air-tight, leak-proof calibration jar was built for this study to measure SVFR and pressure drop for each cyclone-filter combination. A schematic of the design vessel is shown in Figure 2.

The dimensions of the design vessel and a detailed review of preliminary test performed to verify containment (no air leakage) and quantify pressure drop within the vessel were discussed in a previous publication [20].

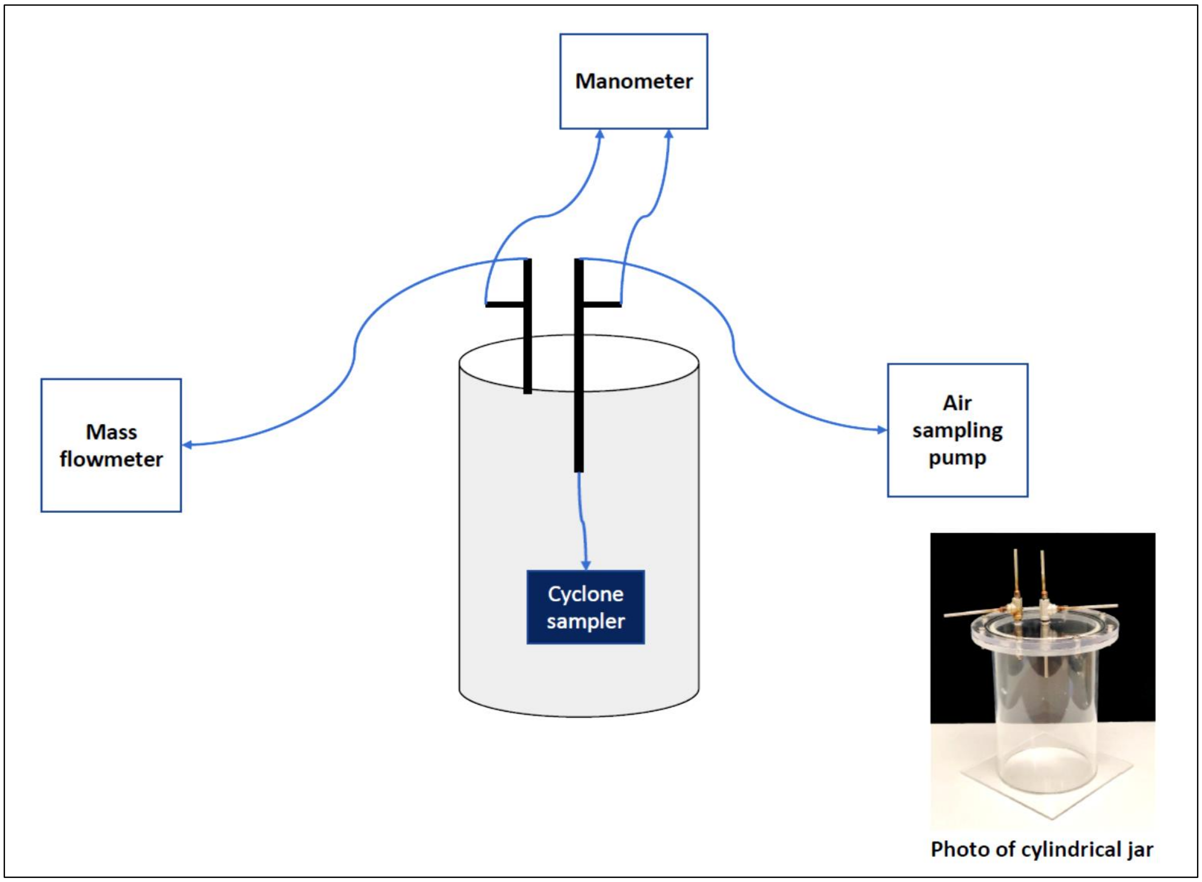

Fig 2. Schematic of design vessel

Sequence of trials:

Three trials were conducted for each cyclone, filter brand and filter lot combination for a total of 72 trials. For each trial, the sampling pump was connected to the digital manometer and a stainless-steel integral bonnet needle valve (SS-1RS6, Swagelok Company, Solon, OH, USA) using a tee connector and flexible tubing. The other end of the valve was connected to the flow meter with flexible tubing. An initial light load was applied by manually adjusting the needle valve, and then the flow rate corresponding to the respective cyclone type was set. The initial light load applied was within the 95% confidence interval of the median pressure drop observed in the prior study (see Table 1). The pressure drop was then increased to a pressure between 25 and 35 in. w.g. by partially closing down the needle valve and the pump was allowed to operate for one minute before recording the final flow rate. The final flow rate was confirmed to be within ± 5% of the initial flow rate. The cyclone assembly was then connected to the digital manometer and sampling pump using a tee connector and flexible tubing. The load created by the cyclone assembly was recorded and compared to the range specified in Table 2. A paired t-test was used to compare the mean pressure drop applied using the needle valve and the mean measured pressure drop of the cyclone assembly. The SVFR set up by the jarless method was then verified for closeness, in the related calibration train (pump + cyclone assembly) without making any additional adjustments to the pump. SVFRs were measured by using: (1) the traditional jar method via a commercial multi-purpose calibration jar (Cat No. 225-112 SKC Inc., Eighty Four, PA, USA); (2) the jar method via the design vessel fabricated for this study, and (3) a calibration adaptor, if available. Paired t-test were used to compare the SVFR measured via the various calibration methods.

Part II:

Part two of the study evaluated the accuracy of the Jarless method by comparing measured SVFRs using different calibration methods (calibration adaptor (if available), design vessel, traditional jar, and jarless)) for various cyclone, filter brand and filter lot combination (see Table 4) for a total of 48 trials. The experimental design of part II replicated that of part I with the exception that the initial flow rate was set by using a pressure drop equivalent to a designated calibration cassette/filter via the jarless method, and replicate samplers (cassette/filter) were used to measure the corresponding SVFRs via the traditional jar, design vessel, and calibration adaptor methods. The aim of part two was to simulate the pre-calibration process in air sampling where a cassette/filter was used for pump calibration and a separate cassette/filter was utilized in the sampling process.

Table 4. Sampling train configurations for Part II

Cyclone Type	**PVC filter, 5.0-µm, 37-mm**	
Aluminum cyclone *(n=1)*	Brand: SKC Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*	Brand: Zefon Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*
10-mm Dorr-Oliver nylon cyclone *(n=1)*	Brand: SKC Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*	Brand: Zefon Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*
Zefon® 10mm conductive nylon cyclone *(n=1)*	Brand: SKC Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*	Brand: Zefon Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*
GS-3 cyclone *(n=1)*	Brand: SKC Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*	Brand: Zefon Lot 1 *(n=4)* Lot 2 *(n=1)* Lot 3 *(n=1)*

RESULTS

Part I:

Data were analyzed using IBM® SPSS® Statistics for Windows, version 25 (Armonk, NY, USA). The pressure drop of the cyclone assembly at the volumetric flow rate specified by the manufacturer, measured under multiple combinations of sampler type, and commercial filter brand, including manufacturing lot, was compared with the initial pressure drop applied when using the jarless calibration method. The measured pressure drop of all cyclone assemblies considered in this part of the study fell within the respective ranges shown in Table 2, indicating the modified pressure drop ranges utilized to set the initial pressure drop in the jarless protocol, were appropriate.

A paired t-test was applied to compare the mean pressure drop applied via the Jarless method with the measured mean measured pressure drop of the related cyclone assembly. Results are shown in Table 5, indicating statistical differences in half of the assemblies under consideration. For the aluminum and GS-3 cyclone, the mean measured pressure drop of the cyclone assembly was not significantly different from the mean pressure drop applied. Conversely, the nylon and Zefon® cyclone, showed a statically significant difference between these two pressures. However, the mean measured pressure drop of the cyclone assembly was still within the allowable range (1 – 2 in. w.g).

Table 5. Comparison of applied vs. measured pressure drop for cyclone assemblies

Cyclone assembly	Mean (SD[A])ΔP[B] applied	Mean (SD) ΔP cyclone assembly	Paired *t* statistic
Nylon	1.174 (0.105)	1.725 (0.355)	$t_{17} = -6.735, p<0.0001$
Zefon	1.773 (0.070)	2.029 (0.365)	$t_{17} = -3.100, p=0.007$
GS-3	2.249 (0.412)	2.422 (0.842)	$t_{17} = -0.720, p=0.481$
Aluminum	2.286 (0.0433)	2.318 (0.861)	$t_{17} = -0.158, p=0.876$

[A] Standard Deviation (SD)
[B] Pressure drop (in. w.g.)

Table 6. Comparison of flow rate measurements using different calibration methods

Cyclone assembly	Calibration Adaptor Mean (SD [a]) SVFR [b] *[Paired t-statistic [c]]*	Design Vessel Mean (SD) SVFR	SKC Jar Mean (SD) SVFR *[Paired t-statistic]*	Jarless Method Mean (SD) SVFR *[Paired t-statistic]*
Nylon	[d]	1.68 (0.01)	1.70 (0.01) [$t_{17} = -13.242, p<0.0001$]	1.70 (0.00) [$t_{17} = -12.852, p<0.0001$]
Zefon	[d]	1.67 (0.01)	1.69 (0.01) [$t_{17} = -11.373, p<0.0001$]	1.70 (0.00) [$t_{17} = -16.157, p<0.0001$]
GS-3	[d]	2.72 (0.02)	2.73 (0.01) [$t_{17} = -7.792, p<0.0001$]	2.75 (0.00) [$t_{17} = -8.199, p<0.0001$]
Aluminum	2.47 (0.03) [$t_{17} = -2.072, p=0.054$]	2.46 (0.03)	2.48 (0.02) [$t_{17} = -5.855, p<0.0001$]	2.50 (0.00) [$t_{17} = -6.066, p<0.0001$]

[a] Standard Deviation (SD)
[b] Standard volumetric flow rate in lpm
[c] Compared to SVFR measured via the design vessel
[d] Option not available

For quality assurance, paired t-tests were applied to verify performance consistency in comparisons of SVFR measurements between a simple manufacturer's calibration adapter and the more complex design vessel fabricated for this study. Since the aluminum cyclone was equipped with a calibration adaptor allowing direct connection to the mass flow meter, the SVFR measured via the calibration adaptor was compared to the SVFR measured using the design vessel fabricated for this study. The mean SVFR measured using the calibration adaptor (2.47 lpm) was not statistically different from the mean SVFR measured using the design vessel (2.46 lpm) *(t_{17} = -2.072, p=0.054)*, indicating the flow rate measured using the design vessel was equivalent to that of a connector with a much simpler and less flow-restrictive configuration. Therefore, the design vessel was considered a reliable option for measuring the "true" SVFR in all subsequent trials. Results of SVFR measurements and a paired t-test has been shown in Table 6. Although all SVFR measurements using the traditional jar and jarless method were statistically different compared to the design vessel SVFR, the difference was within ± 5% which was the maximum allowable difference for pre- and post- calibration flow rates specified by OSHA [17].

Part II:

Paired t tests were applied to compare SVFR measurements obtained in part two of the study using different calibration methods while simulating the pre-calibration process in air sampling where a separate cassette/filter was used for pump calibration. As in part one, the design vessel was considered the "true" SVFR in all trials. Results of SVFR measurements and paired t-tests are shown in Table 7. Although all SVFR measurements using the traditional Jar and Jarless methods were statistically different compared to the design vessel SVFR, these differences were still within ± 5% of the design vessel SVFR.

Table 7. Comparison of flow rate measurements which simulate pre-calibration protocol

Cyclone assembly	Calibration Adaptor Mean (SD [a]) SVFR [b] *[Paired t-statistic [c]]*	Design Vessel Mean (SD) SVFR	SKC Jar Mean (SD) SVFR *[Paired t-statistic]*	Jarless Method Mean (SD) SVFR *[Paired t-statistic]*
Nylon	[d]	1.66 (0.01)	1.69 (0.01) *[t_{11} = -17.234, p<0.0001]*	1.70 (0.00) *[t_{11} = -12.310, p<0.0001]*
Zefon	[d]	1.66 (0.01)	1.68 (0.02) *[t_{11} = -12.539, p<0.0001]*	1.70 (0.00) *[t_{11} = -11.389, p<0.0001]*
GS-3	[d]	2.70 (0.02)	2.72 (0.03) *[t_{11} = -4.529, p<0.0001]*	2.75 (0.00) *[t_{11} = --8.038, p<0.0001]*
Aluminum	2.46 (0.02) *[t_{11} = -2.602, p=0.025]*	2.46 (0.01)	2.48 (0.02) *[t_{11} = -13.000, p<0.0001]*	2.50 (0.00) *[t_{17} = -12.195, p<0.0001]*

[a] Standard Deviation (SD)
[b] standard volumetric flow rate in lpm
[c] compared to SVFR measured via the design vessel
[d] option not available

DISCUSSION

The aim of this study was to provide a detailed review of the jarless calibration method published in the OTM and NMAM 0600. Firstly, the rationale behind the initial pressure drop range specified was examined. In a previous study, the authors observed that the measured pressure drop created by the cyclone assembly (cyclone + cassette) at the manufacturer specified flow rate was oftentimes lower (< 2.0 in. w.g.) that the initial range specified in the jarless method (2 – 5 in. w.g.), particularly for the nylon and Zefon® cyclone [20]. As a result, the challenge pressure utilize in the study was adjusted according to cyclone type (Table 2) and analyses were performed to evaluate the appropriateness of these revised ranges. The measured pressure drop of the cyclone assembly during multiple trials (n=120) involving various combinations of cyclone and filter brand type (including filter lot), fell within the revised range each time, indicating the modified ranges were appropriate.

The second portion of the study was focused on evaluating the accuracy of the jarless calibration method by comparing the SVFR set via the Jarless method to the SVFR measured using an air-tight design vessel. In addition, the SVFR was measured using the "traditional" Jar method and compared to the design vessel SVFR. In part one of the study, trials (n=72) were conducted for multiple combinations of cyclone and filter brand, including filter lot. In part two of the study, trials were repeated (n=48) to simulate the pre-calibration process where a designated unit (cassette/filter) was used for pump calibration and a separate cassette/filter was used in the sampling process. All SVFR measurements using the Jarless method and "traditional" Jar method were within ± 5% of the SVFR measured using the design vessel.

This study did not examine the rationale behind the upper challenge pressure (25 – 35 in. w.g.) recommended by the Jarless method. The purpose of the upper challenge pressure was to ensure the initial flow rate remains relatively unchanged (± 5%) under pressure drop equivalent to that of a fully-loaded sampler. Since air sampling pumps were equipped with back pressure capabilities and pre- and post-calibration was performed to identify errors due to sampler loading or pump malfunction, evaluation of the upper challenge pressure was deemed outside the scope of this study.

CONCLUSIONS

The Jarless method provides a simple approach to cyclone calibration when conducting air sampling in the workplace. A reserved sampler was not required for calibration, the error that can occur due to poor seals in the calibration jar lid was eliminated, and calibration adapters were not necessary. Based on observations from the current study, the authors recommend the initial pressure drop range specified by the Jarless method be modified to account for differences among cyclone types (see Table 2). Overall, the Jarless method provides accurate calibration results utilizing the modified initial pressure drop ranges proposed in this study.

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