

# The Significance of Air Flow Pulsation in Occupational Air Sampling

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## Introduction

In this document we will look at the cause, implications and some of the potential errors associated with flow pulsation levels in medium flow (1 to 5L/min) air sampling pumps.

Air sampling is carried out to ensure that airborne contaminants, whether they come in the form of dusts, particulates, gases or vapours in either the workplace or the ambient environment, are compliant to regulatory standards. Occupational Hygiene and Health and Safety professionals will frequently employ air sampling techniques to assess employee exposure to hazardous airborne substances.

In active air sampling, the air/gas sample is actively drawn into or through a sampling media using an Air Sampling pump. A range of Air Sampling pumps are available which offer different flow rates and performance to suit different sampling strategies. In this paper we consider the influence of Air flow pulsation associated with medium flow sampling pumps, such pumps form the backbone of sampling strategies targeting the assessment of personal exposure to airborne particulate hazards with a typical flow range of approximately 1 to 5L/min.



## The Air Sampling Pump and Flow Pulsation

Air Sampling pumps used for Occupational Hygiene applications are predominantly compact, battery powered and bodily worn devices designed to maintain a 'constant' volumetric flow rate by the use of electronic control circuitry. As we will see shortly, 'constant' inlet flow is not truly 'constant' but in fact represents mean flow value with a superimposed rapidly changing component. These rapid variations in flow are known as Flow Pulsation and are associated to the rotation and fundamental principle of the internal pump mechanism.



Whilst a variety of different pump mechanisms are suitable for air movement, for reasons of achieving maximum flow and pressure performance at very high levels of electro-pneumatic efficiency (*which directly influence the required battery capacity, run time, dimensions and overall product weight*), without exception the pump mechanism of choice used in all personal air sampling pumps is the diaphragm pump.

A diaphragm pump is a 'positive displacement' pump. (*consider the 'positive displacement' effect being similar to the piston being moved in and out of a syringe*)

The basic principle of a single headed diaphragm pump is illustrated in figure 1.

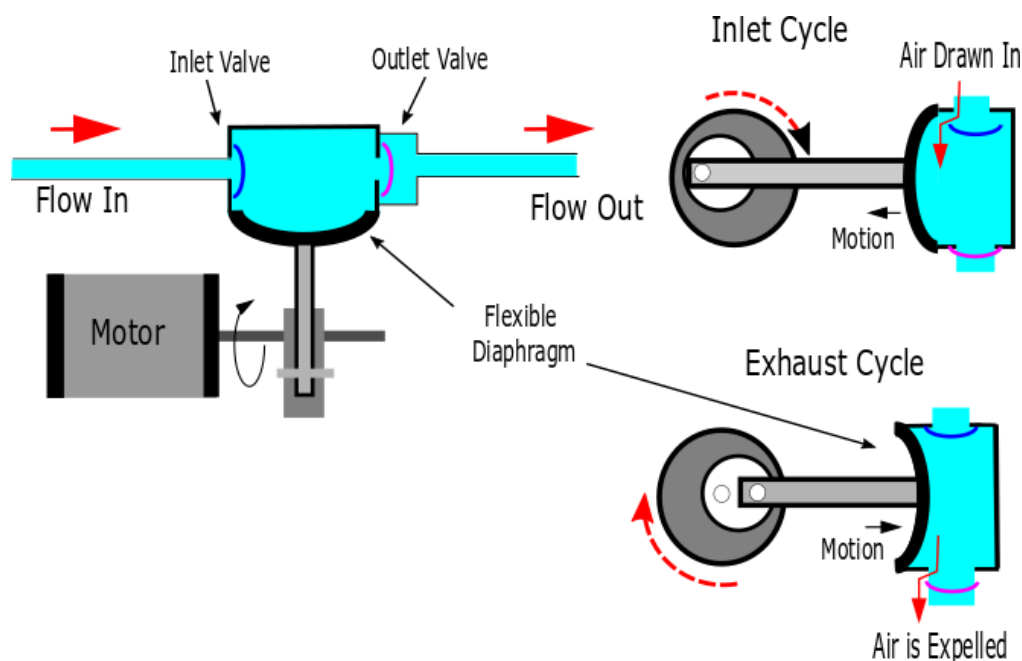


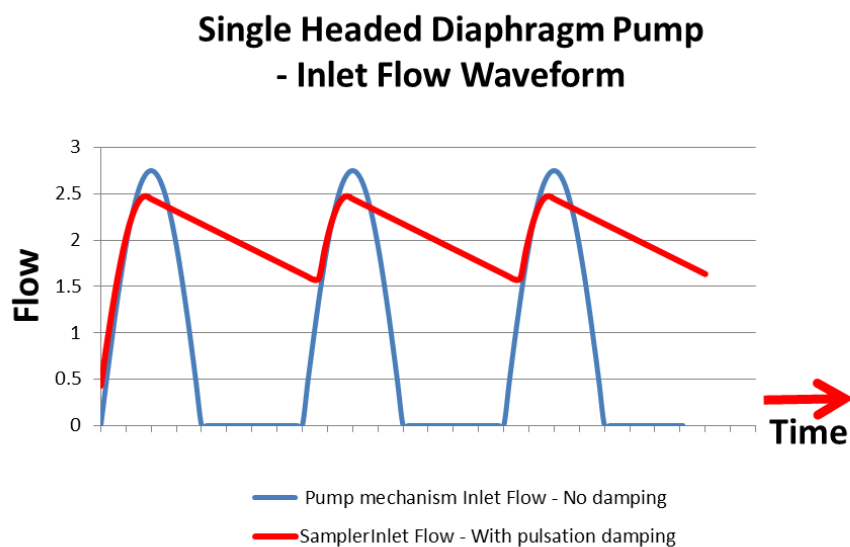
Figure 1 – The Diaphragm Pump



A small electric motor working through a crank or eccentric mechanism creates a reciprocating linear motion in a flexible rubber diaphragm. As the diaphragm moves forwards and backwards, inlet and outlet valves are used to control the movement of air firstly in, and then out of the chamber.

It is important to note that in one rotation of the motor, the pump has two discrete cycles where air is firstly drawn into the pump through the inlet valve before then being expelled via the outlet valve.

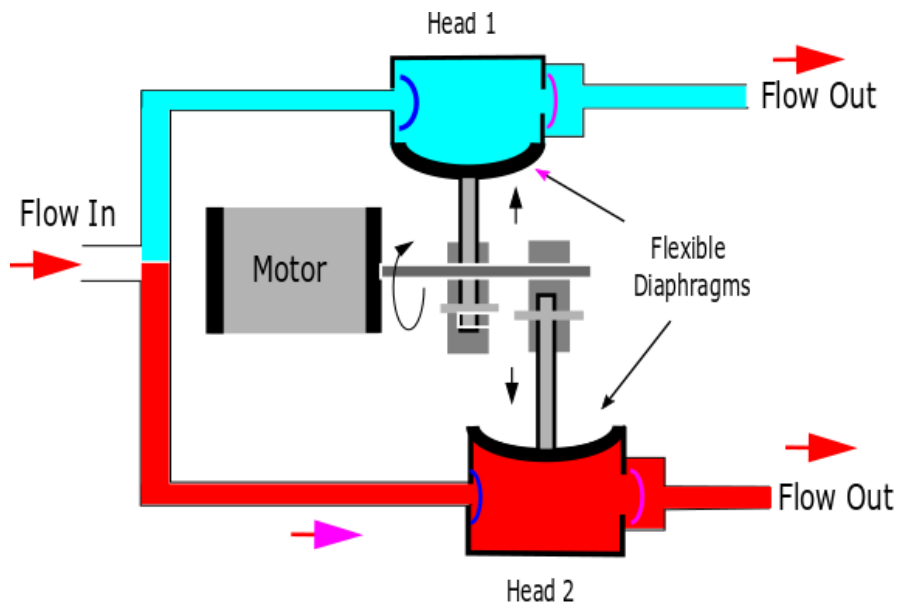
For this 'single headed' pump configuration, the theoretical plot of inlet flow rate would be as shown below:-



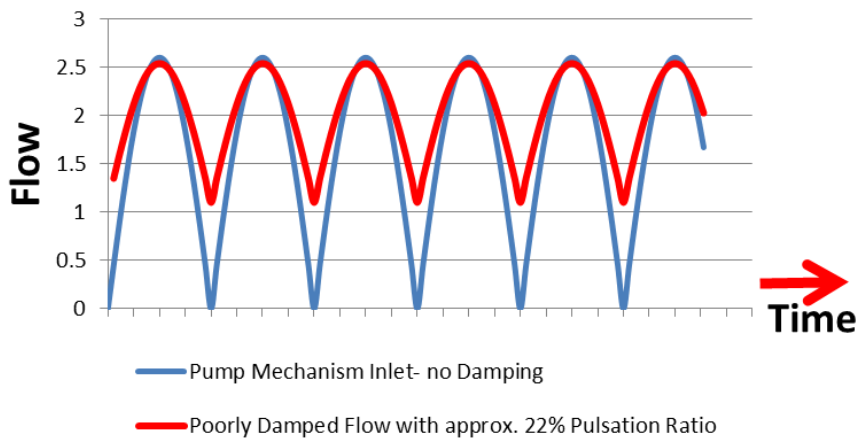
It can be seen that as the pump rotates, air is only drawn into the pump on the inlet cycle. During the outlet cycle air is expelled via the outlet valve. **The undamped inlet flow of a single headed diaphragm pump is in fact zero for half a motor rotation!**

In reality, many (but not all) sampling pumps include an additional pulsation dampening device(s) in the inlet flow path. These are typically formed from a cavity which includes elastic membrane walls. The elastic nature of the pulsation dampener, the compressibility of air, tubing volumes and resonance etc within the inlet flow path will all effectively 'smooth' or 'pulsation damp' the flow of air. The 'real world' waveform of inlet flow will however be significantly more complex than shown here due to the fore mentioned issues and valve performance.

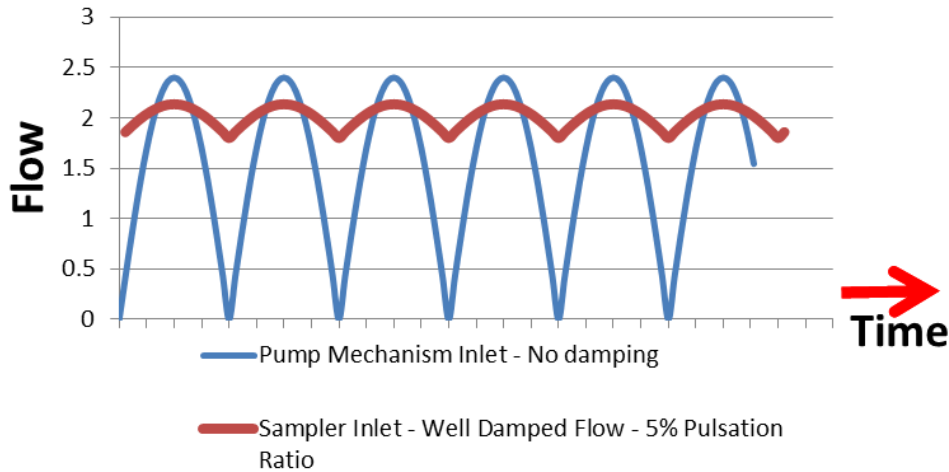
To reduce pulsation, a 'Twin Headed' Diaphragm pump may be used as illustrated below. In this design, each 'head' of the pump works in opposite cycles to maintain inlet flow with no gaps.



## Twin Head Diaphragm Pump - Flow Waveform with Poor Pulsation Damping



## Twin Head Diaphragm Pump - Flow Waveform with Damping



A twin head diaphragm pump has flow pulsations at twice the rotation frequency and at typically half the magnitude of a single headed pump, however, **airflow pulsation is an unavoidable consequence of any diaphragm pump**. By good damper design, the amplitude of flow pulsations can be minimised, but never fully eliminated.

## Measuring Pulsation

An international standard, ISO 13137 defines the Requirements and Test Specifications for personal Air Sampling pumps. Section 5.9 specifies that the flow Pulsation ratio, P, shall not exceed 10% of the mean flow. It is calculated according to:-

$$P = \frac{\sqrt{\frac{1}{T} \int_0^T [f(t) - \bar{f}]^2 dt}}{\bar{f}} \times 100 \%$$

**Where :-**

f(t) is volume flow rate over time t  
 $\bar{f}$  is the mean volumetric flow over time T  
 t is time in seconds  
 T is the total time period of the pulsation

*(Note:- this is effectively represents a ratio of the RMS content of the flow pulsation waveform to the mean flow value).*

The pulsation test is specified to be carried out at 2L/m @ 0.75kpa using a rapidly responding volumetric flow meter or hot wire anemometer. Pulsation amplitude is always worse at low inlet pressures when dampers have reduced effect.

Does this all sound a little too complex and inconvenient? Well, the good news is that the Casella Flow detective has the sampling speed to effectively monitor the flow pulsation waveform in real time and compute the pulsation ratio % in accordance with the above equation. The instantaneous volumetric flow is sampled every 3ms with pulsation ratio and average flow rate computed over the user selectable averaging period of 1 to 60 seconds.

The Flow detective is the first flow meter to monitor and warn of high flow pulsation characteristics exceeding 10% within the sample airflow.

With the ISO13137 standard for personal Air Sampling pumps you may expect all personal air sampling pumps would satisfy the 10% pulsation requirements. However, as various research publications <sup>(1)</sup> and others have noted, many pumps fail to meet this 10% pulsation with some examples exceeding 60% leading to potential sampling problems and errors. With the Casella Flow detective you can now be aware that you have a potential risk of Pulsation errors especially in Respirable or other size selective sampling applications.



# Airflow Pulsation – The hidden problems

## Flow Measurement Accuracy

Many types of flow meter exhibit poor accuracy when subjected to pulsating airflow. Most notably when using a variable area type flow meter (Rotameter) on a high pulsation flow, the float position will become very unstable or move up and down as it attempts to respond to the rapid changes in the airflow. In this situation rotameters will significantly over-read and measurement accuracy will be poor.

Positive displacement meters such as bubble meters or piston type meters exhibit the best immunity to pulsating flow conditions since they accurately measure the time taken for the movement of a specific volume of air.

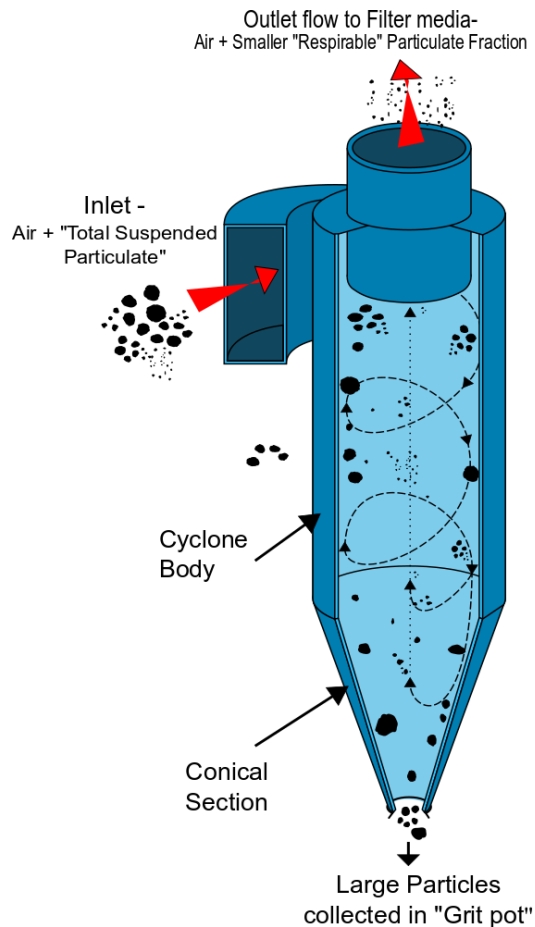
Many electronic flow meter types (orifice, thermal mass flow, differential pressure) may also be subject to errors when measuring complex pulsating air flow. It is necessary for the meters to rapidly monitor the flow at a rate faster than the frequency of the pulsation. The errors can be dependent upon the pumps RPM and filter pressure loading (*pulsation being worse at lower pressures*).

## Size Selective Sampling Head Errors – Cyclones

Size selective heads such as the Cyclones or Impactors are used to collect the smaller, more biologically-relevant aerosol fractions including the Respirable, Thoracic, PM10 or PM2.5 fractions.

The basic arrangement of a cyclone size selective head is shown in figure2 below.





**Figure 2. Cyclone Size Selective Separator**

The sample air enters the cyclone and begins to rotate and descend downwards. As it spins the larger particle sizes follow a trajectory whereby they are effectively spun outwards to the wall surface and drop out by a process known as inertial impaction. The smaller sized particles (of interest) remain suspended in the central vortex airflow which carries them upwards and out of the cyclone to the filter media. The rotational velocity and hence flow rate are **critical factors** in determining the cyclones size cut. Pulsations in the flow alter the effective size cut and various research<sup>(1&2)</sup> papers have shown that the pulsations from some sampling pumps affect the cyclones collection penetration by over 10%. Respirable sampling guidance notes from international bodies (such as NIOSH 0600 and HSE MDHS14-4) identify the importance of using a known low pulsation level.

# Casella Flow Detective – Pulsation Awareness

As we have seen, some sampling pumps lack effective pulsation damping. Whilst this may be irrelevant to some sampling strategies, in a size selective sampling application this can lead to undesirable sampling errors.

For the first time, a flow meter can automatically and reliably warn of pulsation levels exceeding 10% (according to ISO13137). For pulsation levels below 10% the Flow Detective maintains its accuracy of +/- 2%. When the pulsation warning is shown above 10% the measurement accuracy will begin to reduce and it is recommended that efforts are made to reduce the pulsation levels.

Being aware of a high pulsation level makes it is possible to take precautions such as adding an additional flow dampener to the sample line, operating the pump with longer and more flexible tubing, operating with a higher inlet pressure loading to reduce pulsation level, or use a different sampler!

## **Literature References**

1. The Annals of Occupational Hygiene - Journals – NCBI Publications, “Evaluation of Pump Pulsation in Respirable Size-Selective Sampling”  
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4607266/pdf/nihms726843.pdf>
2. The effect of flow pulsations on the performance of cyclone personal respirable dust sampler :- <https://www.sciencedirect.com/science/article/pii/S0021850291900825>

## **Further Reading**

1. Pulsation error effects for different Flow meter types:  
<http://www.diva-portal.org/smash/get/diva2:371890/FULLTEXT02>
2. NIOSH 0600 Respirable Sampling Method  
[http://synectics.net/public/library/StreamResource.axd?DSN=pub&Mode=FileImage\\_Inline&ID=2](http://synectics.net/public/library/StreamResource.axd?DSN=pub&Mode=FileImage_Inline&ID=2)
3. HSE MDHS14-4 Respirable Sampling Guidance  
<http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-4.pdf>

