

Controlling Airflow in Class II Biosafety Cabinets

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Introduction

Class II biosafety cabinets are defined by the National Sanitation Foundation (NSF International) as:

“A ventilated cabinet for personnel, product, and environmental protection having an open front with inward airflow for personnel protection, downward HEPA filtered laminar airflow for product protection, and HEPA filtered exhausted air for environmental protection.”¹

In order to maintain proper containment, NSF stipulates that recirculating and exhausted airflow volumes, and therefore velocities, must be maintained within a tolerance of ± 5 feet per minute (FPM).² HEPA filter loading can compromise a biological safety cabinet's ability to maintain proper airflow. This paper will review the current technologies used by various biosafety cabinet manufacturers to monitor and maintain proper airflows as HEPA filters load.

Manually Controlling Airflow

Differential Pressure Gauges

When biosafety cabinets were originally developed in the 1960s and 70s, built-in electronic technologies for measuring and displaying airflow were prohibitively expensive. To indicate that the cabinet was running properly, most manufacturers opted to equip their cabinets with differential pressure gauges. The differential pressure gauge simply reports the pressure change between points. The most commonly used gauge is known by the trade name Magnehelic™, manufactured by Dwyer Instruments Incorporated. Compared to electronic technologies, these gauges are relatively inexpensive and not susceptible to temperature and humidity fluctuations.

In one configuration, the gauge displays the differential pressure between the positively pressurized HEPA filter plenum and the atmosphere. Another configuration connects the gauge so that it displays the difference between the negatively pressurized rear plenum and the atmosphere. If monitored regularly, the gauge indicates increases in filter pressure, which is caused by the filter loading with particulates. Alternatively, a drop in pressure is usually due to a mechanical fault of the filter or blower.

There are three inherent problems with using a differential pressure gauge to monitor biosafety cabinet performance. First, proper airflow is the key performance factor, not pressure. Second, it takes a catastrophic change to significantly affect the reading on a differential pressure gauge, thus it is not a good indicator of filter loading. Finally, interpreting the gauge



The Purifier® Logic® Biosafety Cabinet is one example of a biological safety cabinet that uses sensorless airflow control.

readings may not be intuitive and since most gauges do not have an alarm to indicate a performance failure, there is potential for users to be exposed to unsafe conditions before performance is restored.

Besides the shortcomings of the gauge itself, biosafety cabinets that solely rely on these gauges require manual adjustment by a certifier when readings indicate that performance has degraded. The certifier can only verify a safe airflow for a single moment in time; as the filter loads over time, the airflow will degrade.

Automatically Controlling Airflow

Sensor-Based Feedback Loops

In the late 1970s and early 1980s, the increased availability and reduced cost of electronic air velocity sensors made this technology a viable solution for biosafety cabinet manufacturers. The first of these cabinets used an airflow sensor, specifically a thermal (hotwire) anemometer (Figure 1), to continuously measure the downflow velocity in a single spot in the work area. The velocity is reported to the biosafety cabinet's speed con-



Figure 1. In biosafety cabinets using sensor-based airflow control, a thermal anemometer measures the downflow velocity in a single spot in the work surface.

troller via a feedback loop. As downflow velocity drops due to filter loading, the speed controller increases the blower speed to return the velocity to its nominal setpoint. The biggest advantages to this technology are real-time airflow monitoring and the display of airflow in the biosafety cabinet. In addition, if an airflow disruption causes an unsafe condition, the biosafety cabinet is capable of alerting the user immediately.

However, there are shortcomings to this design. The thermal anemometer consists of a small wire through which an electrical current is passed. The air passing over the wire cools it proportionately to the air's velocity and the resulting temperature differential is converted to a voltage. The voltage is sent to the controller that must interpret the voltage as an air velocity. Each sensor element responds differently to changing velocities. Therefore, either the controller must be calibrated with its unique sensor or a calibrated sensor with an integral compensation circuit delivering a standardized output must be used. In the first arrangement, when either a sensor or the board fails, then both must be replaced with another matched controller and sensor. In the second case, a sensor failure would only require the replacement of the defective sensor. In either case, replacement can be expensive and requires a trained certifier and recertification of the unit after repairs are completed.

In some cases, these sensors can be sensitive to temperature and humidity fluctuations. Unless the biosafety cabinet is outfitted with a tem-

perature sensor that can automatically correct the sensor's readings for temperature and humidity changes, the sensor may interpret a temperature fluctuation as a change in airflow, causing the biosafety cabinet to alarm. A certifier would need to address the alarm resulting in an added maintenance expense and downtime of the cabinet. In locations where temperature and humidity routinely fluctuate, these alarm situations can prove costly.

The most significant drawback to this technology is in the sensor's lack of accuracy. Typical thermal anemometer sensors used in biosafety cabinets have an accuracy of +/-10%, which allows for a considerable amount of fluctuation. Additionally, most of these designs use a single point reading, typically either downflow velocity or exhaust velocity. The drawback in measuring velocity in a single point is that airflow patterns across the HEPA filter will change as the filter loads with particulates. Therefore, a single point reading may not accurately reflect the overall change in air velocity across the entire filter face. Finally, the sensor itself requires annual recalibration, to compensate for changing airflow patterns in the cabinet, as well as sensor "drift" as it ages.

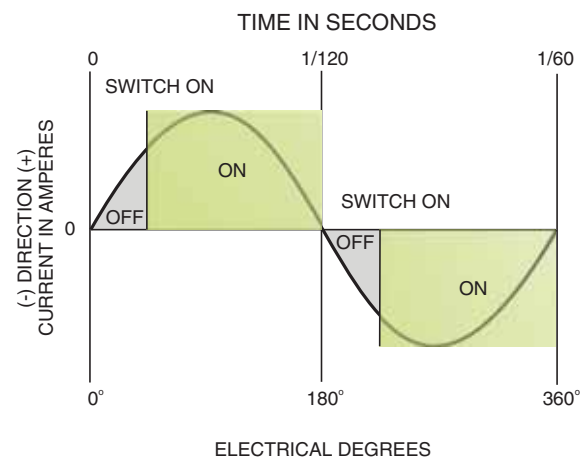
When the design was first introduced, the use of a thermal anemometer to maintain biosafety cabinet performance was a vast improvement over the manually-adjusted speed controls that were originally used. However, its inherent drawbacks have led manufacturers to seek more robust and reliable methods to automatically compensate for changing airflows as the HEPA filters load.

Sensorless Airflow Control

In 2007, Labconco solved the intrinsic problems associated with using sensors to monitor and automatically adjust motor speed to compensate for filter loading. One goal in the development of the Purifier® Logic® Biosafety Cabinet was to incorporate better, more efficient motor technology. To that end, a direct current (DC) electronically commutated motor (ECM) was installed in place of the conventional alternating current (AC) permanent split capacitor (PSC) motor (Figure 2).

A Look Back — PSC motors

Until recently, biosafety cabinet manufacturers strictly used **Permanent Split Capacitor (PSC) motors** to drive the cabinet's fan(s). The speed of the PSC motor(s) is controlled by an electronic circuit that chops the line voltage off and on, as shown in this illustration. The longer the motor is switched off the slower it will run. A voltmeter placed on this circuit registers a decrease in voltage. While this is a very simple and robust design, a chopping speed controller is susceptible to fluctuations in line voltage. In the 1970s and 1980s, some biosafety cabinet manufacturers enhanced the type of speed controller by adding a voltage-compensating circuit. When properly designed, the voltage-compensating speed controller will maintain a constant (chopped) motor voltage. Unfortunately, a voltage-compensating speed controller cannot automatically adjust the motor speed required as the HEPA filters load.



Self-Compensating Blowers

SIDE BAR

Most biosafety cabinets in service today have blowers with forward curved fans. These blowers exhibit a “self compensation” as the HEPA filters load. As the HEPA filters load, and their differential pressure increases, the forward curved fan begins to “slip,” and the motor speeds up, much like a car’s engine speeds up when its drive wheels hit an icy surface. The amount the fan “self compensates” depends on the blower, the motor, and how much the load has increased. Although there is some compensation with a forward curved fan, it is not based on the airflows in the biosafety cabinet, but on the slippage of the fan. Self compensation is a mechanical feature, unrelated to automatically controlling airflow by means of sensors or CAP. Both ECM and PCS motors exhibit self compensation.



Figure 2. Electronically Commutated Motor (ECM)

The ECM offers numerous advantages over earlier PSC technology. Its inherent efficiency offers an energy savings of 50% or more, while its rugged design provides an operational lifespan approximately three times longer than the PSC motor. The cooler operation of the ECM minimizes the rise in air temperature in the working environment of the biosafety cabinet, promoting user comfort. Microprocessor sensing and control of motor speed and torque allow for the programming of the motor to deliver constant air volume to the biosafety cabinet even as HEPA filter loading changes.

Constant Airflow Profile (CAP) Technology

The process of “teaching” the ECM to deliver constant airflow volume is a patent-pending process developed by Labconco, called the Constant Airflow Profile (CAP). In order to program the ECM to maintain a nominal airflow, Labconco engineers recorded the speed and torque requirements of each size cabinet at a variety of different airflows and HEPA filter differential pressures. The speed, torque and airflow data was processed using software provided by Regal Beloit to generate a unique performance profile for the ECM (Figure 3).

With this patent-pending process, Labconco’s CAP technology has solved the previously encountered problems with airflow monitoring. As discussed previously, thermal anemometers require routine calibration. With CAP technology, there are no sensors to recalibrate or replace. Therefore, maintenance and equipment replacement costs for maintaining these air-

flow monitoring devices have been eliminated. In addition, this robust design is not susceptible to temperature and humidity fluctuations that can plague thermal anemometer-based systems.

Perhaps the most beneficial advantage to this design is its inherent accuracy. Testing performed at Labconco Corporation has demonstrated that

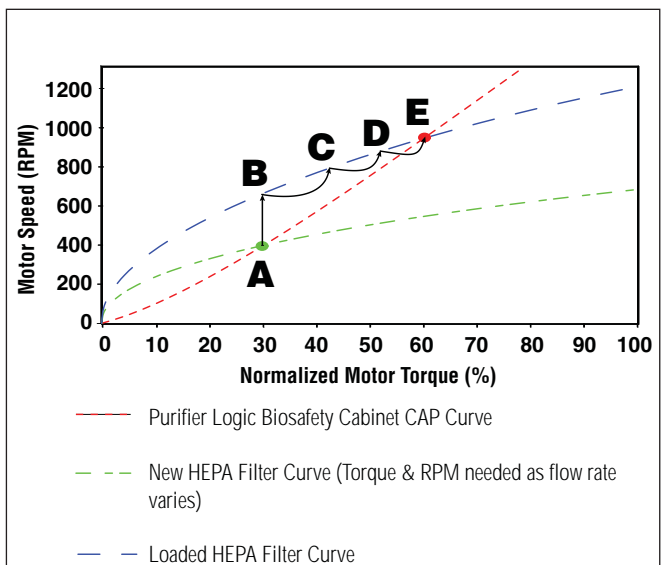


Figure 3. This graph illustrates how the ECM motor maintains constant airflow. The Constant Airflow Profile (red) line indicates the motor torque and speed required to maintain a constant volume of 800 cubic feet per minute (CFM). This line is programmed into the motor as a series of constants generated during the characterization process. The green dashed line represents the starting filter pressure in the biosafety cabinet. As the HEPA filters load, the new pressure will be represented as the blue dashed line. The biosafety cabinet is operating stably at point “A,” until the filters load. The blower then speeds up to point “B,” a result of increased pressure and reduced airflow. This increase in speed (referred to by some as “self-compensation”) happens with any type of motor (See the “Self-Compensating Blowers” side bar for further discussion). Unlike the PSC motor, that would remain at point “B,” the ECM checks its speed and torque. Because point B is not on the Constant Airflow Profile line, the ECM increases its speed and torque to points “C,” “D,” and finally “E” until its speed and torque fall back onto the red line.

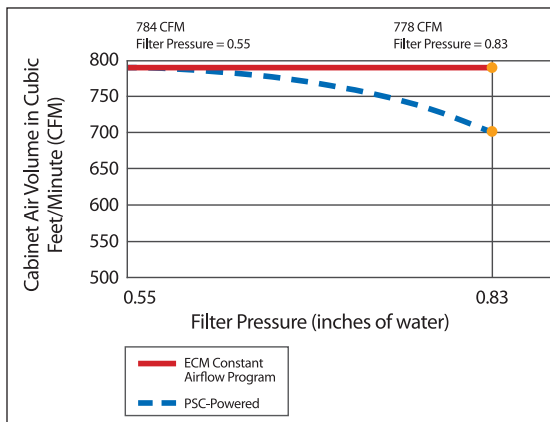


Figure 4. This graph illustrates actual test results from NSF International on a Purifier Logic Type A2 Biosafety Cabinet powered by an ECM with CAP technology and a biological safety cabinet powered by a PSC motor. In the Motor/Blower Performance Test as defined in ANSI/NSF Standard Number 49, a new biological safety cabinet's total volume of air displaced by the blower is measured. The cabinet's front grille is then restricted to simulate an additional 50% load on the HEPA filters. The total volume of air is measured again, and compared to the initial value. In the graph shown, the Purifier Logic Biosafety Cabinet with the CAP technology saw its volume decrease from 784 to 778 CFM, a loss of 0.7% (represented by the red line). The biosafety cabinet with the PSC motor saw a loss of approximately 60 CFM, or 8% (represented by the blue dashed line). These results demonstrate that the Purifier Logic Biosafety Cabinet maintains accurate airflow by more than tenfold compared the PSC-powered biosafety cabinet.

airflow is maintained with only a 1-2 % difference in airflow as the HEPA filter loads. Figure 4 shows a representative data sample from this study.

Conclusion

Significant strides have been made in the last forty years to maintain constant airflows in biosafety cabinets. Simple chopping circuits and differential pressure gauges have given way to sensor-based control systems. These, in turn, are now being supplanted by sensorless microprocessor-motor systems, which are capable of maintaining accurate airflow volume even as the cabinet's HEPA filters load (Figure 5). One sensorless system uses Constant Airflow Profile (CAP) technology, which offers the advantages of tenfold more accuracy, reliability and the elimination of periodic recalibration of airflow sensors to ensure proper airflow.

References

¹ NSF International, "NSF/ANSI 49 - 2009: Biosafety Cabinetry: Design, Construction, Performance, and Field Certification." 2009, p. 5.

² Ibid., p. 28.

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Biological Safety Cabinet Airflow

| Control Comparison | Differential pressure gauges | Sensor-based feedback loops | CAP technology |
|--|------------------------------|---------------------------------------|----------------|
| Automatic airflow adjustment | NO | YES | YES |
| Accuracy of airflow control | Not applicable | +/-10%* | +/-2% |
| Airflow sensor maintenance, replacement cost | \$ | \$\$\$ | 0 |
| Susceptible to temperature & humidity fluctuations | NO | Sometimes. Depends on sensor used. | NO |
| Visual alarm display | NO | YES | YES |

Figure 5. This chart summarizes the three types of airflow control mechanisms used on biological safety cabinets currently available.



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